EJTIR

Issue 12(1), 2012
pp. 88-110
ISSN: 1567-7141
www.ejtir.tbm.tudelft.nl

A Very Long Term Forecast of the Port Throughput in the Le Havre – Hamburg Range up to 2100

Cornelis van Dorsser[1]
Faculty of Civil Engineering and Geosciences, Delft University of Technology, the Netherlands

Milou Wolters[2]
Rijkswaterstaat Center for Transport and Navigation, the Netherlands

Bert van Wee[3]
Faculty of Technology, Policy and Management, Delft University of Technology, the Netherlands

This paper presents a new methodology for the development of a probabilistic very long term forecast of the total port throughput in the Le Havre – Hamburg range up to 2100. The forecast is based on a combination of System Dynamic Modelling, Judgement, and Causal Relations. It is intended to provide infrastructure planners with some guidance on the very long term development of transport demand over the lifetime of the infrastructure. On the basis of the forecast it can be expected that the port throughput in the Le Havre – Hamburg region will remain growing throughout the first half of the century, but at a reduced pace. Towards the end of the century throughput volumes will stabilize or even decrease. The notion of decreasing and stabilizing throughput volumes will help infrastructure planners to consider the (ultimate) capacity to be provided beyond the current expansion plans as well as the type of expansions that will suit future demand some 20 to 30 years from now.

Keywords: Long Term, Probabilistic Forecast, Port Throughput, Le Havre-Hamburg Range.

1. Introduction

Very long term predictions of about 30 to 200 years are not uncommon for topics like energy, environment, and climate change. These topics require a very long term view because the inertia of the relevant processes in systems (e.g. global temperature increase) requires a very long time to adjust. Infrastructure is often designed for a lifetime of up to 100 years. Once in place it defines the characteristics of the system for a long period of time. The planning of transport, energy and other infrastructure networks therefore also requires a long term view. Only a few long term studies in the field of transportation exist, the worldwide forecasts of Schäfer et al. (2009) being

[1] PO Box 5048, 2600 GA Delft, the Netherlands, T: +31152782811, E: j.c.m.vandorsser@tudelft.nl.
[2] PO Box 5044, 2600 GA Delft, the Netherlands, T: +31887982531, E: milou.wolters@rws.nl.
[3] PO Box 5015, 2600 GA Delft, the Netherlands, T: +31152781144, E: g.p.vanwee@tudelft.nl.

an example. An obvious reason for the low number of forecasts is that it is very difficult to forecast for this period. Most transport studies do not look further than 20 to 40 years ahead and good forecasting methods for an even longer term are lacking. This leaves transport infrastructure planners with a gap for most of the anticipated lifetime.

A common way to deal with long term developments is the use of scenarios, but (storyline) *"scenarios are not predictions"* (Schwartz, 1991, p.6) as they say little (or nothing) on the likelihood of occurrence. Armstrong (2001, p.517) advocates the use of scenarios to gain acceptance for forecasts but warns not to use scenario techniques to provide forecasts. In practice two different scenario approaches can be observed. The first approach uses well thought storylines in order to think through certain events and allow decision makers to be prepared for sudden changes. These are for instance the scenarios adopted by Shell in the early 70's (Schwartz, 1991, p.7). The second approach uses scenarios for evaluation of various policy alternatives. This approach requires a balanced set of more or less equally likely scenarios amongst a wide range of plausible futures. An elegant way to develop a balanced set of scenarios is to base them on a probabilistic forecast. By doing so, it can be 'guaranteed' that the scenarios are more or less equally likely and cover a wide range of anticipated futures. This approach has for instance been applied by IIASA in the development of a set of population scenarios for the Millennium Ecosystem Assessment (www.iiasa.ac.at).

In the Netherlands Rijkswaterstaat is responsible for most of the hydraulic structures on the inland waterways. To meet future challenges Rijkswaterstaat now investigates the possibility to develop a very long term substitution strategy up to 2100 (Heijer et al., 2010). Historically there has been a strong link between the development of the Dutch ports and waterways. About 60% of the cargo volumes transported by inland barges has an origin or destination in the seaports (PRC, 2007, p.7). A prediction of the future development of the port throughput therefore helps to anticipate future use of the Dutch inland waterways. Using the Netherlands as an example this paper aims to present a methodology for the development of a probabilistic very long term forecast of the total port throughput in the Le Havre – Hamburg Range up to 2100 and to discuss the results. The presented forecast is intended to contribute to the development of balanced set of very long term scenarios for the transport volumes shipped on the Dutch inland waterways, but it can be used in other studies as well.

Section 2 provides a review of methods applied in the field of port throughput forecasting, long term forecasting, and other long term studies. On the basis of these findings a probabilistic forecast method is proposed. The method is based on the assumption of a general relation between GDP and port throughput. Section 3 analyses this relation, Section 4 obtains the required GDP forecast, and Section 5 finally prepares the forecast of the port throughput. The conclusions and further discussions are presented in Section 6.

2. Forecasting Methodology

How to provide a 90 year forecast for the Le Havre – Hamburg range? Section 2.1 to 2.3 presents the results of a desk study aiming to answer this question. Section 2.4 proposes a three step forecast methodology that will be applied in this paper.

2.1 Review of Port Throughput Forecasting Methodology

On the basis of a desk study and various discussions with experts it had to be concluded that there does not exist a handbook on port throughput forecasting. Forecasts are generally prepared by port authorities or specialised consultants and based on causal relations between port throughput and demographic, economic, or industrial developments. Literature supports the use of causal relations. In particular the relation between economic activity (measured in GDP) and freight transport (measured in tonnes or tonne kilometres) is often recognised[4].

A review of port throughput forecasting articles has revealed that the subject has not received much attention. A search on Scopus and Google Scholar provided seven relevant articles of which full text documents were accessible[5]. It is interesting to observe that most of these articles do not relate to the causal models applied in practice. Instead they refer to methods that are somehow based on mere trend extrapolation of historic time series such as *autoregressive integrated moving average models* (Klein, 1996), *vector autoregressive models* (Veenstra and Haralambides, 2001), *grey models* (Guo et al., 2005), and *neural networks* (Weiqun and Nuo, 2003; Li et al., 2008; Chen and Chen, 2010). By definition models based on mere trend extrapolation of historic time series are not appropriate for the development of a very long term forecast. The same is also likely to hold for models based on a combination of autoregressive and causal relationships such as the *vector error correction model* applied by Fung (2001).

Hui, Seabroke and Wong (2004, p.196) discussed that the *"classical regression"* (as usually applied in many practical forecast studies) identifies causal relationships by measuring the co-movement between variables. They warn that this approach is only valid if the data series are stationary and not showing any trend over time. *"This is because for trending variables, even if they are completely independent, they often move in the same direction under the common trend, creating an illusion of causal relationships"*. The illusion that unrelated variables hold a causal relationship is referred to as spurious regression. Problems with spurious regression can be avoided by using of a first-differences model. However, *"a first-differenced model considers only short-run adjustments which relate how changes in one variable correlate with changes in another. It neglects the underlying long-run relationship linked by the levels or the original (nondifferenced) values of the variables"*. Under certain conditions the regression of two non-stationary series does not result in spurious regression. If this is the case the error term of the regression is stationary and the variables are referred to as co-integrated. For co-integrated series an alternative model approach can be applied which is referred to as the error correction model (ECM). Important is that the ECM is only valid if the variables in the long term equation are co-integrated. In other words, if a true relationship between these variables exists. In the case of Hui et al. (2004, p.197) the initial linear forecast model was not co-integrated and therefore a log-linear model was applied.

2.2 Review of Very Long Term Forecasting Methodology

A review of 12 mainstream textbooks and 2 leading journals on forecasting was carried out. The textbooks generally refer to the long term as anything over 2 or 3 years. A clear framework for dealing with long term issues was not found. Six textbooks provided some guidance on the topic[6]. The results are listed in Table 1.

Makridakis et al. (1998, p.451-481) is the only author writing a full chapter on the subject. In this chapter reference is made to the construction of scenarios and the use of analogies. In addition to the latter others refer to the use of causal relations, long term (economic) trends, qualitative estimates (such as expert judgements, panel consensus, Delphi, and nominal group process), technological s-curves, Bayes' theorem, and systems dynamic modelling.

---

[4] See for example Meersman and van de Voorde (2008, p. 67-92) and Ickert et al. (2007, p.7).

[5] Some articles published in the *Journal of Wuhan University of Technology* and *Journal of Shanghai Jiaotong University* where not accessible from the Delft university library are therefore not included in this study.

[6] Bails et al. (1993) and Bowerman et al. (2005) indicate that the long run is generally over two year in the future, Clements et al. (1998), Diebold (2004), Mentzer et al. (1998) and Pindyck et al. (1997) do not make any reference to (very) long term forecasting methods.

Table 1. Results of Desk Study on Forecasting Methodology

No.	Reference	Long Run	Issues Discussed with respect to Long Term Forecasting
1.	Armstrong, J.S, ed. (2001)	N/A Note: Armstrong (1985) states > 2 years	Use of scenarios advocated to gain acceptance for forecasts, but not as method for preparing long term forecasts. Section on diffusion of innovations. Discussion of qualitative and judgemental methods that may be applicable to long term forecasting.
2.	DeLurgio (1998)	3 to 20 years	Chapter on *"Technological and Qualitative Forecasting Methods: Long-Term Forecasting"*: Use of different techniques for various time horizons. Discussion of qualitative methods and technological growth s-curves that to may be applicable to long term forecasting.
3.	Hanke et al. (2008)	N/A	No explicit reference made to long term forecasting: Discussion of methods applicable to long term forecasting such as technological s-curves, judgemental forecasts, scenario's and Bayes' theorem.
4.	Levenbach et al. (2005)	> 2 years	No explicit reference made to long term forecasting: Use of different techniques for various time horizons. Discussion of methods that may be applicable to the long term such as qualitative forecasting methods, systems dynamic modelling, and causal relations.
5.	Makridakis et al. (1998)	N/A	Chapter on *"Forecasting the long-term"*: Use of mega-trends, analogies, and scenarios as an attempt to visualise a number of possible futures and consider their implications.
6.	Wilson et al. (2009)	N/A	No explicit reference made to long term forecasting: Use of different techniques for various time horizons. Discussion of methods that may be applicable to the long term such as qualitative forecasting methods, causal relations, and s-curves.

The notion that very long term forecasting has not received much attention is also supported by a review of articles published in the *Journal of Forecasting* and the *International Journal of Forecasting*. Apart from some articles on the use of scenarios hardly anything has been published on the subject of long term forecasting. This was already mentioned by Fildes in 1986 who wrote in the editorial section of the 2nd volume of the *International Journal of Forecasting* (p.4) that *"The editors have not yet published much work directly addressing the question of how to improve long-range forecasts"*. Twenty years later in a 25 year review of the two forecasting journals and their contribution to forecasting research Fildes (2006, p.420) had to reconfirm his previous statement as he wrote that *"There has also been little work on longer term forecasting issues"*. Only recently there has been some attention to the subject as the International Journal of Forecasting (Vol. 23, Issue 4, 2007) published a special edition on *"Global Income Growth in the 21st Century"*.

The fact that little attention is paid to long term issues in forecasting literature is probably related to the fact that it will be inevitable to move beyond mere trend extrapolation and bring insight into the forecast. In this respect reference should be made to the subfield of Bayesian forecasting[7]. West and Harrison (1999, p.20) indicate that *"Bayesian statistics is founded on the fundamental premise that all uncertainties should be presented and measured by probabilities"*. Bayesian forecasting requires a priori statements on the distribution, mean and variance of all the parameters applied in the model. As a result it clearly takes all known uncertainty levels into account in the forecast.

2.3 Review of Methods applied in other Very Long Term Studies

The field of *very long term studies* is still relatively new. In 1972 the Club of Rome attempted a first quantitative prediction on the potential future of the world towards 2100 (Meadows et al., 1972,

[7] Bayesian forecasting refers to the use of statistical methods in forecasting. It has been named after Bayes' theorem of conditional probabilities. This field has been completely ignored by the mainstream textbooks on forecasting. Journals pay somewhat more attention to the subject. A special issue on "Bayesian Forecasting in Economics" was recently published in the International Journal of Forecasting (Vol. 26, issue 2, 2010).

p.27). The method was based on system dynamic approach, but the results shocked the world and raised an intense discussion on the validity of quantitative predictions. Influenced by this discussion, scenarios remained the most common way of dealing with future uncertainty. Scenarios generally have a time span of 20 to 40 years, but for some major issues such as *population*[8], *energy*[9], *climate change*[10] and the *rise of sea water levels*[11] longer horizons up 2100 have been applied over the past two decades. To shape a broad view on the future the *Intergovernmental Panel on Climate Change* (IPCC, 2007) developed 40 different scenarios amongst four different story lines. The use of more than four scenarios is however not recommended (Schwartz, 1991, p.28). Others like Goodess et al. (2007, p.11) therefore suggest to combine multiple scenario runs of various models into a single probabilistic view. Alternatively the *International Institute for Applied Systems Analysis* (IIASA) once again applies probabilistic methods such as system dynamic modelling for population projections (Lutz, et al., 2007). In case of deep structural uncertainties conditional probabilistic scenarios can be applied (van Vuuren et al., 2008). In this approach the major uncertainties are represented by scenarios and for each scenario the confidence intervals are calculated.

2.4 Methodology applied for the 90 year Forecast up to 2100

Port throughput forecasting literature points in the direction of trend extrapolation techniques and the use of causal relations. Forecasting literature indicates that mere trend extrapolation techniques are not suitable for long term estimates, but causal relations are. The relation between GDP and transportation of goods was already mentioned. A similar relation is also likely to hold between GDP and port throughput because port throughput is a function of import and export of goods, which are both a function of GDP[12]. It is however the question if a one variable model is not far too simple for such a complicated issue? We argue that this does not have to be the case. There are good reasons to keep the model simple. According to Bankes (1993, p.439) forecasting models differ from other scientific models as they do not allow for ex-ante validation of the results by means of obtaining additional sample data. Therefore they are sensitive to *"false reduction"* or *"the belief that the more details a model contains, the more accurate it will be. This reductionism is false in"* the sense *"that no amount of detail can provide validation, only the illusion of realism"*. The longer the time horizon forecasted the more sensitive the model becomes to false reduction. For this reason we find a one variable model appropriate as long as it has sufficient explanatory power[13].

---

[8] Examples: Estimate of world population up to 2200 (UN, 1999); Estimate of world population per country up to 2300 (UN, 2003); Four global scenarios up to 2100 by the Working Group for the Millennium Ecosystem Assessment (Charpentier, 2005); Four national scenarios for development of population growth in the Netherlands (de Jong, 2008); Stochastic forecasts for the development of the world population divided into 13 regions (IIASA, 2007). Stochastic forecasts up to 2050 for 18 countries of the EU (Alho et al., 2004).

[9] The Very Long Term Energy and Environmental Model (VLEEM) of the European Union runs up to 2100. The model defines the energy development over one century, worldwide (B. Chateau et al., 2003).

[10] The IPPC Climate Change Synthesis Report (2007) provides scenarios and bandwidths for CO_2 Emissions, the development of Greenhouse gasses (GHG), and related Temperature Rise up to 2100.

[11] For the rise of the sea level in front of the Dutch coast the KNMI provided a bandwidth forecast up to 2100 in 2006. This forecast has been reviewed and extended to 2200 by the Deltacommissie (Veerman, 2008, p. 24).

[12] Using a simple macroeconomic model the economic output (Y or GDP) equals the sum of Consumption (C), Investments (I), Government Spending (G), and Exports (X) minus Imports (M). This is reflected by the formula $Y = C + I + G + (X - M)$. If we assume that exports are a fraction of production (economic output) and imports are a fraction of generalized consumption (C + I + G) than: $X = a\ Y$ and $M = b * (C + I + G)$. If we further assume that the imbalance between exports and imports is small compared to the GDP than we can say that $C + I + G \sim Y$ or $M \sim b * Y$. By definition port throughput is a function of exports and imports: $PT = f(X, M)$. Therefore $PT = f(a*Y, b*Y)$ or $PT = f(a*GDP, b*GDP)$. Or simplified: $PT = f(GDP)$.

[13] We think our forecast model has sufficient explanatory power to provide useful results and therefore we consider a one variable model appropriate. If for some reasons one would like to improve the model by adding

Standard regression theory provides the means to calculate prediction intervals. This theory can be applied to develop a probabilistic port throughput forecast on the basis of a probabilistic GDP forecast. To the best of our knowledge, probabilistic GDP forecasts are not available. Nevertheless they can be obtained by multiplying the following parameters[14]:

- The population of the working age class;
- The labour participation fraction of the working class;
- The annual number of hours worked per employee;
- The development of the GDP output per hour worked.

The proposed methodology therefore consists of three steps. In the first step a probabilistic forecast of the working age population is obtained on the basis of system dynamic modelling. The next step applies (expert) judgement to define (Bayesian) assumptions with respect to the development of labour participation, annual working hours, and GDP output per hour. On the basis of the latter a probabilistic GDP forecast is obtained. Finally the probabilistic forecast of the port throughput is obtained by applying the causal relation between GDP and port throughput. The calculations are prepared with stochastic simulation techniques such as Monte Carlo. In order to reduce the complexity of the forecast presented in this paper it has been assumed that it is appropriate to obtain and use a Dutch GDP forecast instead of a regional GDP forecast. This assumption can be justified by the fact that the economies of the Netherlands, France, Belgium and Germany are closely related and the fact that the GDP of these countries followed a similar trend over the past 110 years (refer Figure 1). For simplicity the applied Dutch population forecast has been compiled from various sources.

3. The Relation between GDP and Port Throughput

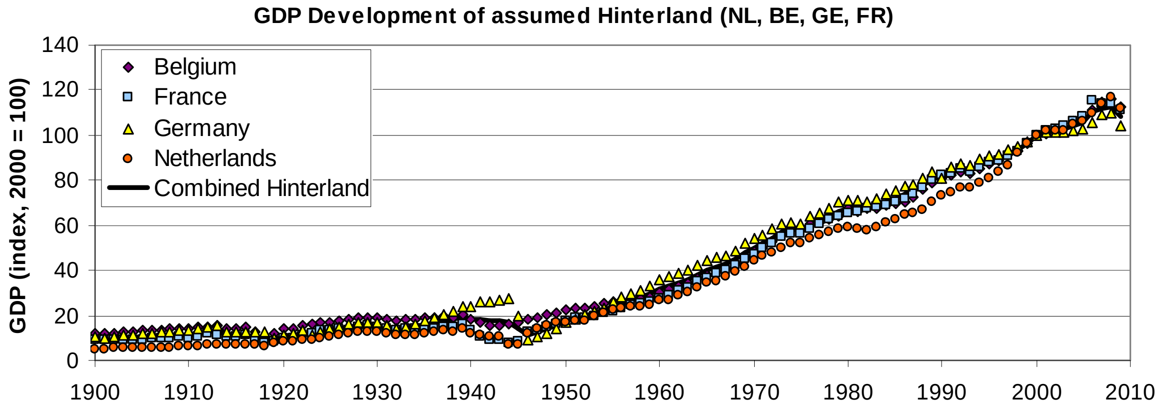
The proposed methodology builds on the assumption of a general long term relation between GDP and Port throughput. This section therefore starts with an analysis of the relation between GDP and port throughput. It analyses the available long term data, selects the two most appropriate relationships, and justifies the use of a combination of these two relations in order to obtain a very long term forecast of the port throughput.

3.1 GDP development for the Hinterland of the Le Havre – Hamburg port region

The Le Havre – Hamburg range does not serve a distinct number of countries exclusively. The actual boundaries of the region are vague and contain overlap with other port regions. Therefore a pragmatic approach has been applied in which the Hinterland is defined as: The Netherlands, Belgium, Germany and France. This simplification is justified by the fact that integrated economic regions tend to move simultaneously – and we are not interested in the actual throughput of the ports per unit of GDP, but in the way that GDP and Port Throughput move along together. To allow for comparison between countries the GDP of the Hinterland has been measured as an index of the year 2000. Figure 1 shows the historic development of the GDP in the assumed Hinterland.

additional variables the most likely candidates would be *fuel prices*, *dematerialisation*, and *globalisation and regional trade patterns – see section 6.*

[14] This methodology has for example also been proposed by Bergheim (2008, p.35).



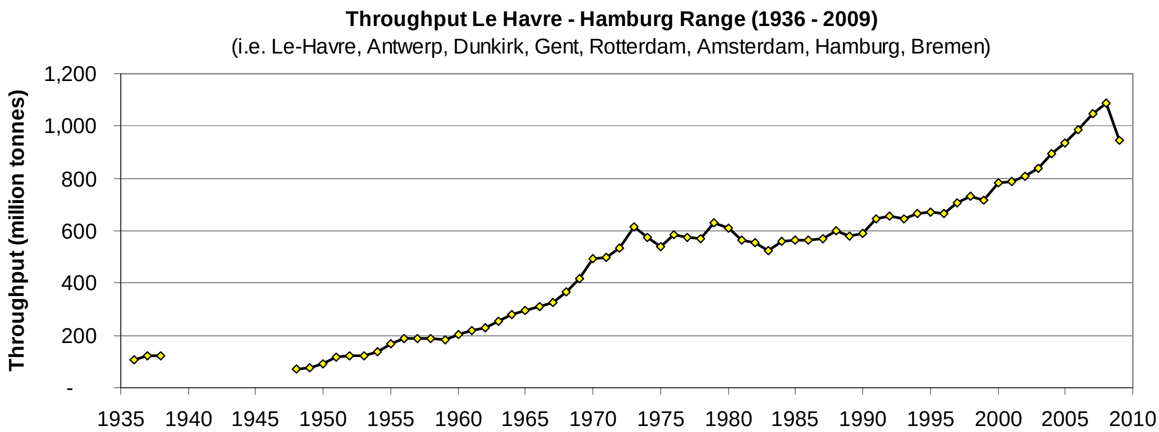
Source: GDP Index derived from Real GDP data of Maddison (2010)

Figure 1. Historic development of GDP in the Hinterland of the Le Havre – Hamburg range

Figure 1 shows that the GDP of the selected Hinterland areas follows a similar trend. Growth has generally been quite stable though a trend breach can be observed at the instance of the Second World War.

3.2 Port Throughput data for the Le Havre – Hamburg range

The Le Havre – Hamburg range contains many seaports of various sizes. The Rotterdam Port Authority includes the ports of Le Havre, Dunkirk, Zeebrugge, Antwerp, Gent, Flushing & Terneuzen, Rotterdam, Amsterdam, Wilhelmshaven, Bremen, and Hamburg in their statistics but provides only a few years of data on their website (www.portofrotterdam.com). Long data series from 1936 onwards (excluding 1939-1947) were obtained from the Antwerp Port Authority for the ports of Le Havre, Dunkirk, Antwerp, Gent, Rotterdam, Amsterdam, Hamburg and Bremen (refer Figure 2).



Source: Port of Antwerp (1936-2007), Port of Rotterdam (2008, 2009)

Figure 2. Historic development of throughput volumes in the Le Havre – Hamburg range

The forecast presented in this paper refers to the eight ports summarized in Figure 2. For 2008 and 2009 these ports accounted for about 90% of the total throughput in the Le Havre Hamburg range (based on statistics of Rotterdam Port Authority).

3.3 Evaluation of the relation between GDP and Port Throughput

The relation between GDP and Port Throughput has been defined on the basis of regression analysis, but regression of time series is not straight forward as the basic assumptions of the regression model are often violated[15]. In order to obtain a suitable forecast relation three simple linear relations have been considered (refer Equation 1 to 3).

$PT_t = \alpha + \beta \cdot GDP_t + \varepsilon_t$ (Equation 1)

$\ln(PT_t) = \alpha + \beta \cdot \ln(GDP_t) + \varepsilon_t$ (Equation 2)

$\Delta PT_t = \alpha + \beta \cdot \Delta GDP_t + \varepsilon_t$ (Equation 3)

with:

α : Intercept value,

β : Linear coefficient,

PT_t : Port Throughput level in year t,

GDP_t : GDP index level in year t,

ΔPT_t : Difference in Port Throughput between year t and year t-1,

ΔGDP_t : Difference in GDP index between year t and year t-1,

ε_t : Error term in year t.

The results of the regression analysis are summarized in Table 2 and Figure 3 to 5.

Figure 3 shows the results of the simple linear regression between the levels of the GDP and port throughput. A clear trend can be observed that holds throughout the data series. However, from the regression statistics it should be concluded that one has to be careful with the interpretation of the model. The error term is highly autocorrelated and likely to contain a unit root. Therefore the model is likely to be misspecified in the sense that it is sensitive to trend breaches of common drivers such as globalisation. Besides this the prediction intervals are too small as a result of the virtually high fit. Finally the error term does not follow a normal distribution and therefore a small additional error in the calculation of the prediction intervals will occur if the standard interval estimation techniques are applied (as in Figure 3).

Figure 4 shows the results of the log-model. The forecast value can be calculated indirectly by taking the exponent of Equation 2 or directly by applying Equation 4.

$PT_t = EXP(\alpha + \varepsilon_t) \cdot GDP_t \hat{} \beta$ (Equation 4)

From Equation 4 it becomes clear that the coefficient β has a special meaning. It equals the elasticity between GDP and port throughput. For this reason double logarithms are often used in transport literature. It is however not likely that the elasticity will remain constant over time. Figure 4 (right) indicates that there remains autocorrelation in the error term. This is confirmed

[15] Granger and Newbold (1974, p.111) provided a clear warning on "spurious" (meaningless) regression. They warn that regression of two time series, that follow an upward or downward trend, can result in a virtual correlation that in reality does not exist. The standard methodology for hypothesis testing and goodness of fit is only valid if the regression parameters are stationary, or in a special case where the time series are co-integrated (i.e. the error term is stationary). In practice many time series are non-stationary and referred to as following a random walk or containing a unit root. If a time series follows a random walk the effects of a temporary shock will not dissipate after several years, but instead remain.

by the regression statistics. Though it seems to appear from the Dickey-Fuller statistics that the logarithms of GDP and port throughput are stationary, this is not the case as the error term is non-stationary and any linear combination of stationary series would have also been stationary. Therefore, unlike the case presented by Hui et al. (2004) the log-linear model is not stationary and still misspecified.

Equation 3 relates the annual differences in GDP to the annual differences in Port Throughput (refer Figure 5). The basic statistics indicate that this model no longer contains a unit root and has a normal distributed error term.

Table 2. Historic development of cargo volumes in the Le Havre – Hamburg range

GDP-Throughput Relation	Equation 1	Equation 2	Equation 3
Data			
- DF-test GDP/ln(GDP)/ΔGDP	1.85	49.93	10.05
- Unit Root**	Yes	No	No
- DF-test PT/ln(PT)/ΔPT	1.90	10.68	17.59
- Unit Root**	Yes	No	No
Function			
- F-test	1402*	2390*	65
- R^2	0.957*	0.974*	0.516
- Adjusted R^2	0.956*	0.974*	0.508
- Durbin-Watson Statistics	0.23	0.25	2.06
Intercept α	-39.92	1.28	-17.46
- t-Stat	-2.52*	13.11*	- 3.55
Linear Coefficient β	8.76	1.19	20.76
- t-Stat	37.44*	48.88*	8.06
Error Term ε			
- DF-test on Error Term	1.79	2.82	32.16
- Unit Root**	Yes	Yes	No
- JB-Statistics	7.89	5.20	0.28
- Normal Distributed**	No	Yes	Yes

Note: (*) meaningless value due to non-stationary error terms; (**) the value "Yes" for unit roots in (or normality of) the error term implies that the hypothesis could not be rejected at the 95% confidence level.

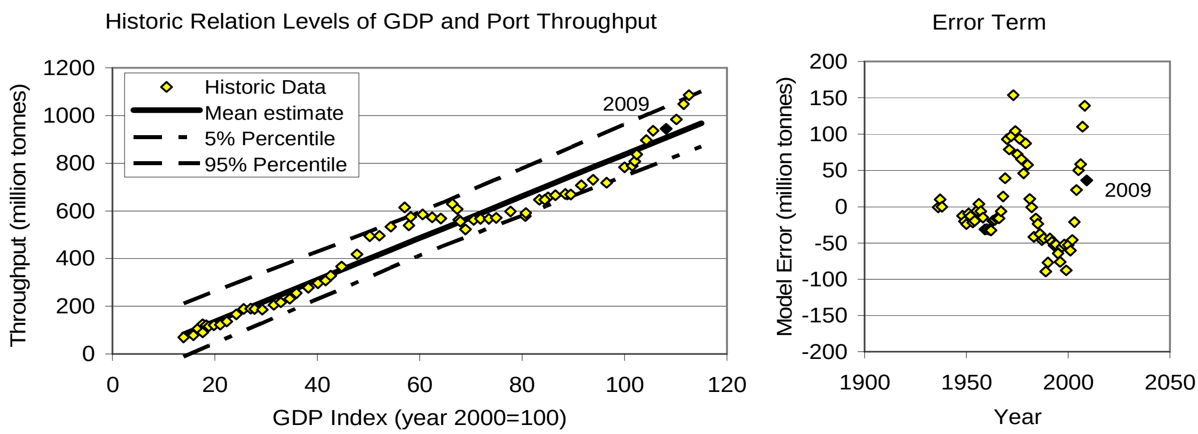


Figure 3. Simple Linear Regression between levels of GDP and Port Throughput

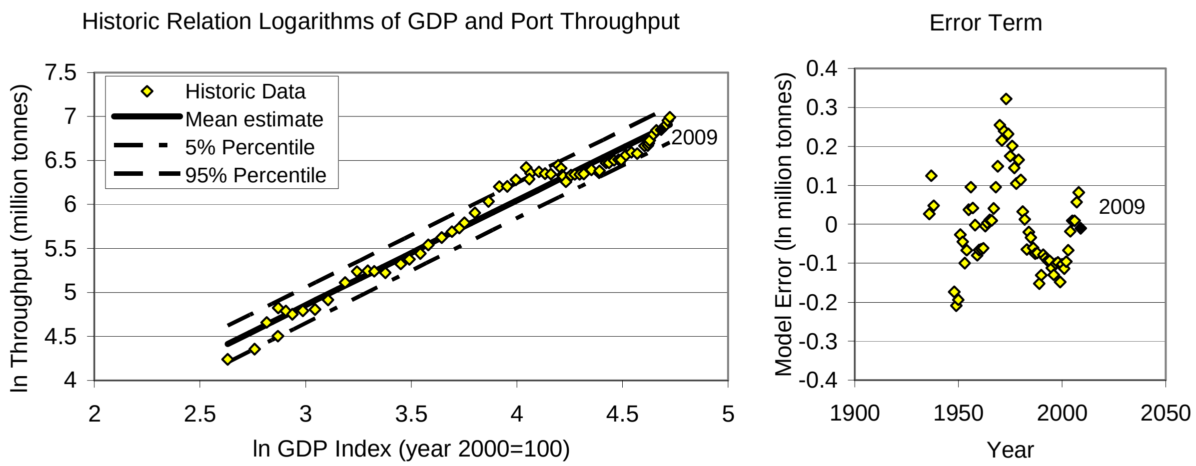


Figure 4. Linear Regression between natural logarithm of GDP and Port Throughput Levels

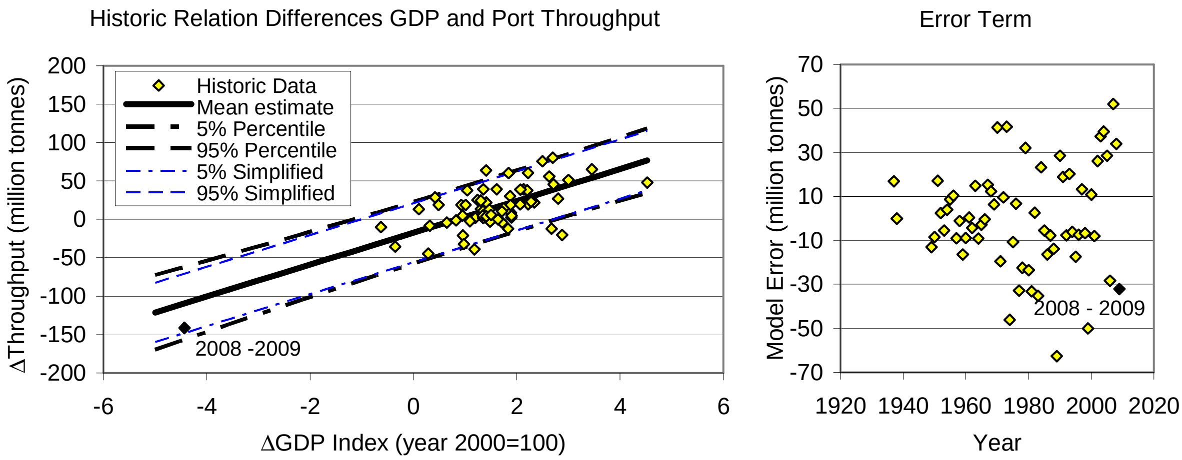


Figure 5. Linear Regression between differences of GDP and Port Throughput

There are not many observations related to a decline in GDP. The exception is the 2008-2009 value. It is difficult to judge whether this value should be regarded as valuable information or as an unwelcome outlier. For the purpose of this paper it has been argued that there is no reason to exclude the data point. However, if the data point would have been excluded the absolute value of the α coefficient would have been 40% lower (at value of -10.42) and the β coefficient would have been 20% lower (at value of 16.72).

Equation 3 can not be used to derive the throughput levels directly from the GDP. In order to obtain a forecast the last observation (at t=0) is taken as a starting point. For each succeeding year the annual change in throughput is derived from the annual change in GDP and added to the value of the previous year. The main problem with this approach is that the calculation requires the growth path of the GDP to be known. This is not the case in our probabilistic forecasts. A simplified approach that directly relates the throughput value to the GDP is provided by Equation 5. This equation however still has the less obvious complication that the error term (required in the simulation process) is path dependant. This problem can be solved by neglecting the variance of the line (i.e. the β coefficient) in the prediction interval. The simplified prediction intervals in Figure 4 indicate that this approach is acceptable.

$$PT_{t=n} = PT_{t=0} + n \cdot \alpha + \beta \cdot (GDP_{t=n} - GDP_{t=0}) + \sum_{t=1}^{n} \varepsilon_t \qquad \text{(Equation 5)}$$

with:

n : Number of years forecasted ahead,

α : Annual decrease in throughput at constant GDP,

β : Linear coefficient between throughput and GDP,

PT_t : Port Throughput in forecast t-years ahead,

GDP_t : GDP in forecast t-years ahead,

ε_t : Stochastic error term of forecast in year t.

Now we have derived a statistically sound relationship the next question is whether it still holds from a theoretic point of view. The negative α coefficient indicates that port throughput will decrease with a constant annual value as soon as the GDP stabilizes. Theoretical evidence supports the existence of a negative α coefficient. A possible explanation is the increased share of services and virtual goods in the economy that results in a decoupling of transportation and economic growth. On the contrary it can also be argued that the existence of a constant negative α coefficient is fundamentally wrong on the very long run as it implies that port throughput drops to zero after the anticipated stabilisation of the GDP (refer section 4). This contradicts the fundamental theory of comparative advantage of David Ricardo. The very long term perspective therefore requires a model with an α coefficient that phases out gradually. To verify if the decline in α can be observed from historic data a multiple regression model containing dummy variables for each decade was built. Empirical evidence of this model could however not support the theory of a declining α coefficient. Therefore we were unable to develop a sound forecast model with a declining α coefficient.

It should be concluded that none of the evaluated forecast equations is completely 'sound' from a statistical and theoretical point of view. Equation 1 and 2 are likely to be misspecified because the variables (or error term) contain a unit root. Applying an error correction model to Equation 1 and 2 is also not appropriate because the error term contains a unit root and therefore the data series are not co-integrated. From a statistical point of view only Equation 3 is not misspecified, but theoretical arguments prove that this model will also be wrong on the very long run. The topic discussed in this paper is however so important that we still find it appropriate to consider the use of the causal relation for providing an order of magnitude estimate of the port throughput. Therefore, in order to further investigate the performance and potential use of the forecast equations an ex-post forecast has been prepared.

3.4 Ex-post performance of the regression models

The ex-post forecast assumes that someone back in 1970 had perfect foresight on the development of the GDP and was asked to develop a forecast of the port throughput up to 2009 on the basis of post war data. The results of this forecast as well as the real development of the port throughput over the past four decades are indicated in Figure 6.

From the results it can be concluded that the difference approach has performed remarkably well as it shows almost no deviation from the true development of the port throughput. The use of the levels approach is also not bad from a very long term perspective as it appears to be unbiased towards the long term trend. The use of an exponential model derived from the natural logarithms of the levels of GDP and port throughput should be avoided as it deviates significantly from the real trend[16]. The results of the (ab)used error correction models are not much different from the long term trends of Equation 1 and 2.

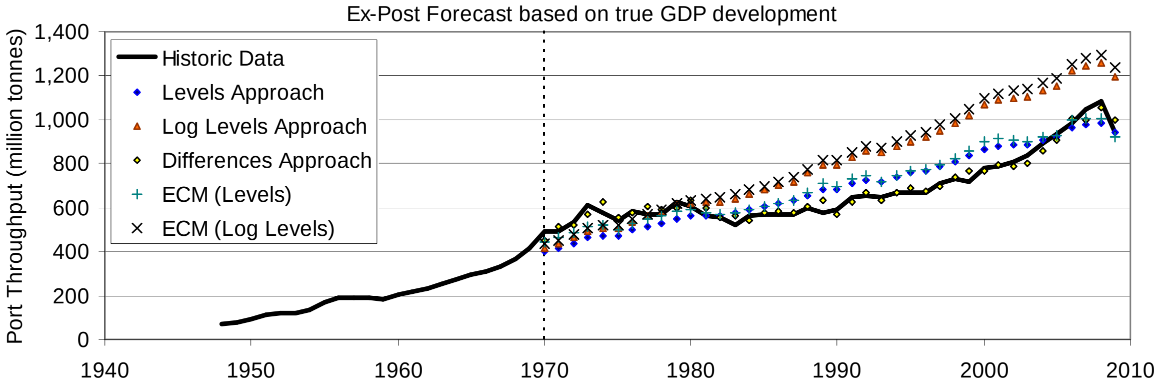


Figure 6. Ex-Post forecast from 1970 to 2009 for various forecast equations

3.5 Justification and suggested approach

Given the excellent results of the ex-post forecast for Equation 1 and 3 the concerns with the statistical and theoretical soundness of the model may be exaggerated. There is no guarantee, but there is strong evidence that supports the use of a combination of these models. There is over seventy year data showing a strong significant long and short term relationship between GDP and port throughput. The long term relation of Equation 1 has not shown a trend breach at the instance of the Second World War and has not changed as a result of the shift from an industrial to a services orientated industry nor from to the rise of the four Asian Tigers or China. On the basis of the above argumentation it can be concluded that the causal relation between GDP and port throughput is extraordinary strong and likely to withstand new global trends such as a shift of production from China back to Europe or to new industrial nations like India or Brazil. This justifies the use of Equation 1 and 3.

An important reason for the existence of a strong causal relationship is the high level of aggregation applied in the model. The results will be completely different if more detail is taken into account. For instance the shift from coal to oil as a bunkering fuel for seagoing vessels in the early 20th century had little effect on the total throughput but reshaped the balance between dry bulk and liquids. On an aggregated level the impact of a serious trend breach will be far less than on a disaggregated level. There is no guarantee that for instance soaring energy prices will not have a large (temporary) effect on future throughput. However, high fuel prices may be offset by a reduction in transportation speed (at least for sea going ships) and further affect both GDP as well as port throughput. Therefore the overall effect on the relation between GDP and port throughput is probably not even that large. In addition, alternative fuels (such as shale gas, algae-fuel, etc.) may cap future energy tariffs causing relatively cheap transportation on the very long run. Over the past 70 years the world has countered periods with high and low energy prices. Energy price risks are therefore included in the variance of the causal relation. In general a similar argument can be made that on an aggregated level the effects of structural societal changes will to a certain extent be included in the variance of the causal relationship.

Forecasting literature indicates that it is good practice to combine forecasts in order to obtain more stable results. This is particularly the case when it is uncertain which method provides the

[16] There is a tradeoff between statistical soundness and theoretical soundness of the model. The logarithm is often taken to avoid misspecification of model but this comes with the risk of developing the wrong model.

most accurate forecast (Armstrong, 2001, p.417). On the very long run Equation 1 is vulnerable to trend breaches that most likely will have a negative impact on the throughput volumes. Equation 1 is therefore likely to overestimate the trend. On the contrary Equation 3 is expected to underestimate the very long term trend as a result of the constant negative α coefficient. Combining both forecasts is therefore expected to reduce bias. The same holds for the bandwidth of the prediction intervals. Due to misspecification of the model the prediction intervals of Equation 1 are too small. This implies that the model assumes common drivers like globalisation to hold on throughout the forecast. On the other hand the variance of Equation 3 completely ignores the existence of common drivers and therefore the prediction intervals will be too wide. In reality some drivers will hold on for quite a while and others will disappear. Therefore a forecast based on the average forecasts of Equation 1 and 3 is expected to provide a reasonable indication of the order of magnitude and uncertainty related to the future port throughput volumes in the Le Havre – Hamburg region.

4. Obtaining a Probabilistic Population and GDP Forecast

The forecast methodology requires a very long term probabilistic forecast of the Dutch GDP. This section provides the required probabilistic GDP forecast on the basis of a probabilistic population forecast and various assumptions with respect to labour productivity.

4.1 Obtaining a probabilistic population forecast

A probabilistic forecast of the Dutch population and the Dutch working age population of 20 to 65 years old has been compiled from three different sources. These sources include the *probabilistic projections for West-Europe of the World Population Program* (IIASA, 2007 update, www.iiasa.ac.at), the *probabilistic projections for the Dutch population up to 2050 of the project Uncertain Population of Europe* (Alho and Nikander, 2004), and *four very long term scenarios for the development of the total population up to 2100* (Jong, 2008). The compiled population forecasts and prediction intervals are indicated in Figure 7 and 8.

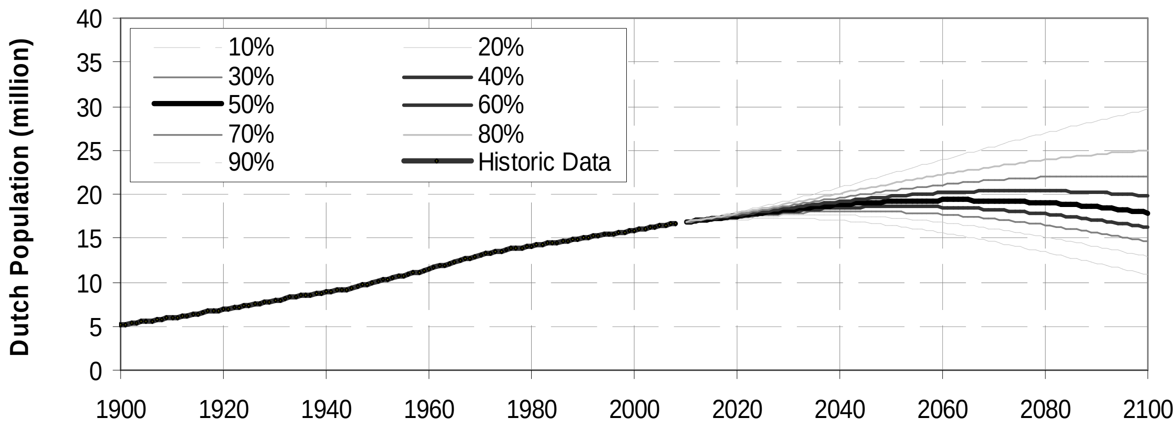
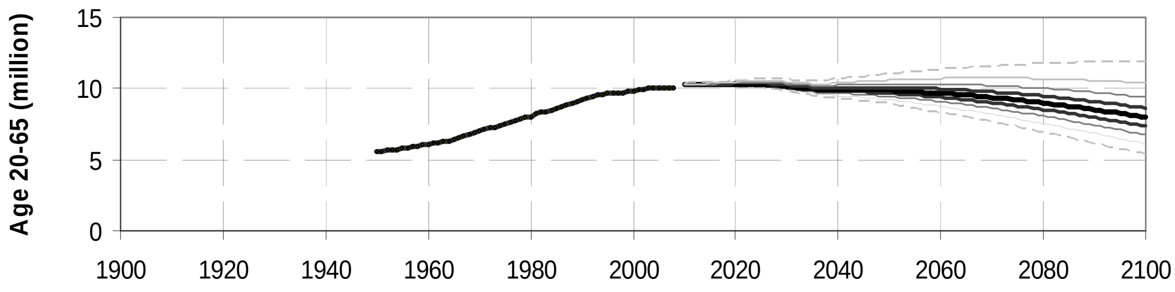


Figure 7. Probabilistic Forecast of the development of the Dutch Population

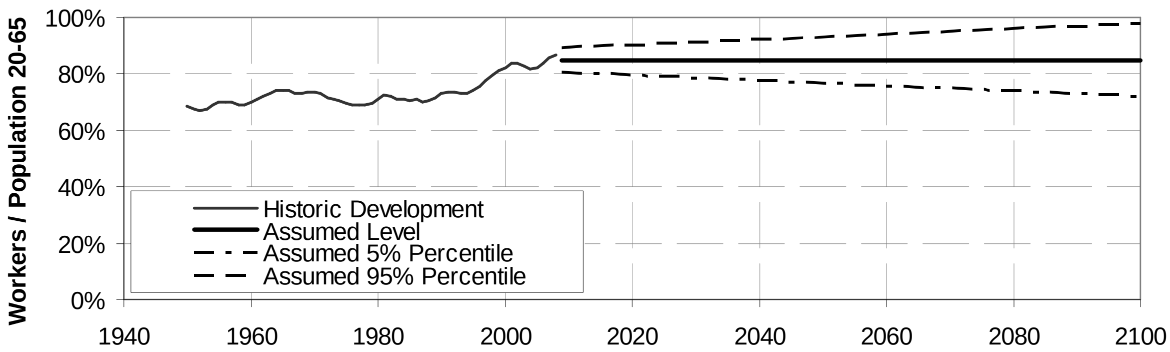


Source: Historic Data obtained from Maddison (2010) and CBS (2010)

Figure 8. Probabilistic Forecast of the development of the Dutch working age Population

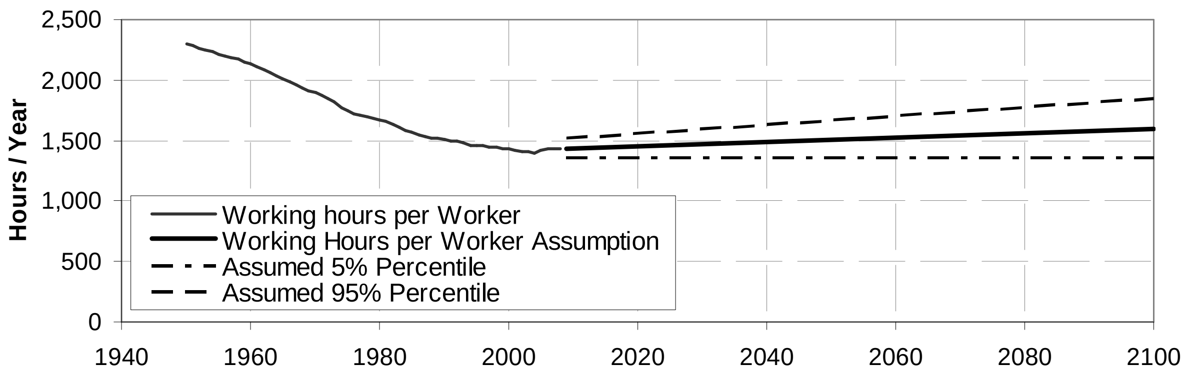
4.2 Obtaining a probabilistic GDP forecast

For the development of the Dutch GDP forecast we have made some (Bayesian) assumptions with respect to labour participation, annual working hours, and GDP output per hour on the basis of (expert) judgement. The final GDP forecast is derived by sampling the product of working age population and the various assumptions made. The assumptions with respect to labour participation and working hours are indicated in Figure 9 and 10.



Source: Historic Data has been obtained from the Dutch National Bureau of Statistics (www.cbs.nl) and The Conference Board (2009)

Figure 9: Assumed development of the Labour Participation in the Netherlands

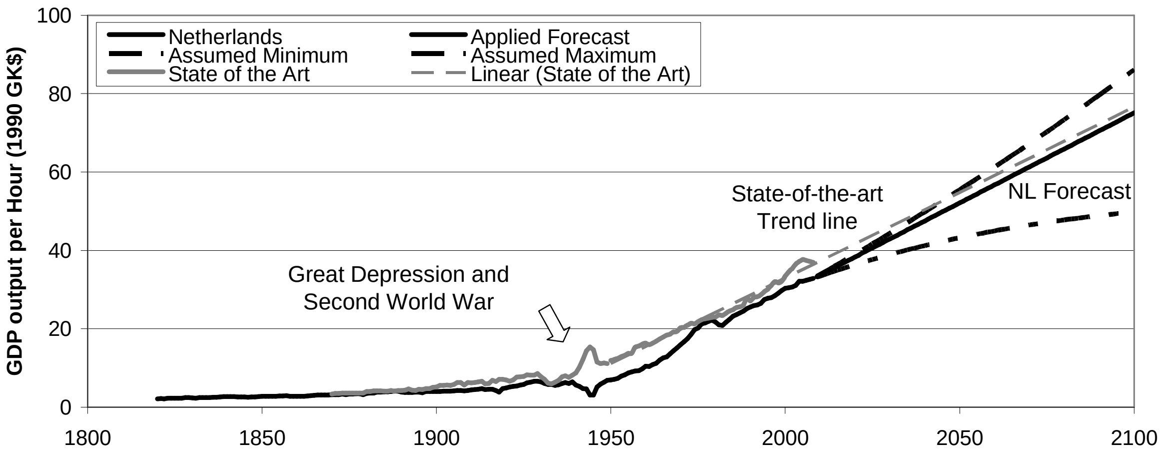


Source: Historic Data has been obtained from The Conference Board (2009)

Figure 10: Assumed development of Annual Working Hours per Worker

Over the past 60 years labour participation has increased considerably but at the same time the annual working hours have plunged. Given the high level of participation and the anticipated relative shortage of working age population it can be expected that the labour participation will remain more or less stable and that there will be some pressure on the working hours. For this reason it is assumed that the mean estimate for the labour participation rate will remain constant at a level of 85%. The related variance is assumed to be normal distributed with a standard deviation of 3% in 2009 increasing to 8% in 2100. The annual number of working hours is assumed to increase from 1435 hours in 2009 to 1600 hours in 2100. The related variance is assumed to be normal distributed with a standard deviation of 50 hours in 2009 increasing to 150 hours in 2100.

Unlike labour participation and working hours the development of the labour productivity is not bounded by any (known) physical limits. Long term data series were studied to define the long term trend. Figure 11 shows the historical data and applied forecast assumptions.



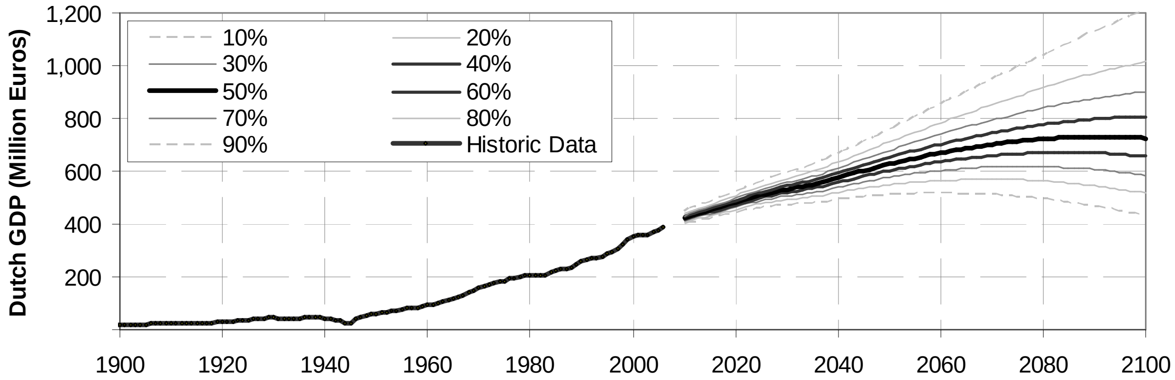
Source: Historic Data from Maddison (2010) and The Conference Board (2009).

Figure 11: Assumed development of the Labour Productivity

The gray line indicates the hourly labour productivity for the most productive country in the world. This line is referred to as *state-of-the-art*. The black line indicates development for the Netherlands. Both lines show a trend breach at the instance of the Great Depression and Second World War. The state-of-the-art trend line shows a strong linear trend since the early 1950s[17]. The black line indicates the development of the labour productivity for the Netherlands. From the end of the Second World War the Netherlands is performing well and slowly creeping towards the state-of-the-art trend line. The forecast assumptions of the Dutch GDP per hour worked have been defined as a triangular distribution function of which the main estimate follows a linear extrapolation of the post war trend. The maximum is defined by a 15% increase imposed on the trend in 2100. This causes an upward shift of the state-of-the-art line. The minimum is defined by a 30% fall compared to the long term trend in 2100. The downward risk is perceived larger than the upward risk as it is not difficult for a country to fall behind (the analysed data provided many examples of such behaviour). Shifting the state-of-the-art trend line to a higher level is however far more difficult.

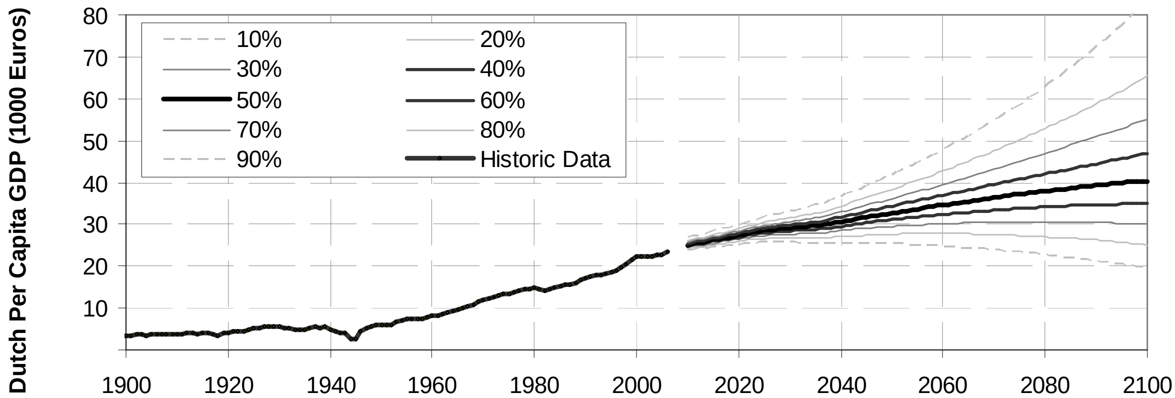
[17] The small hub over the last decade (2000-2010) can be observed. This hub is related to a temporary increase in oil prices that shifted the Norwegian GDP beyond the long term equilibrium. It does therefore not mark a potential breach of the long term linear trend.

The Dutch GDP and GDP per capita forecasts are derived on the basis of the population forecast and Bayesian forecast assumptions. The results are indicated in Figure 12 and 13.



Source: Historic Data obtained from Maddison (2010)

Figure 12. Probabilistic Forecast for the development of the Dutch GDP



Source: Historic Data obtained from Maddison (2010)

Figure 13. Probabilistic Forecast for the development of the Dutch GDP per Capita

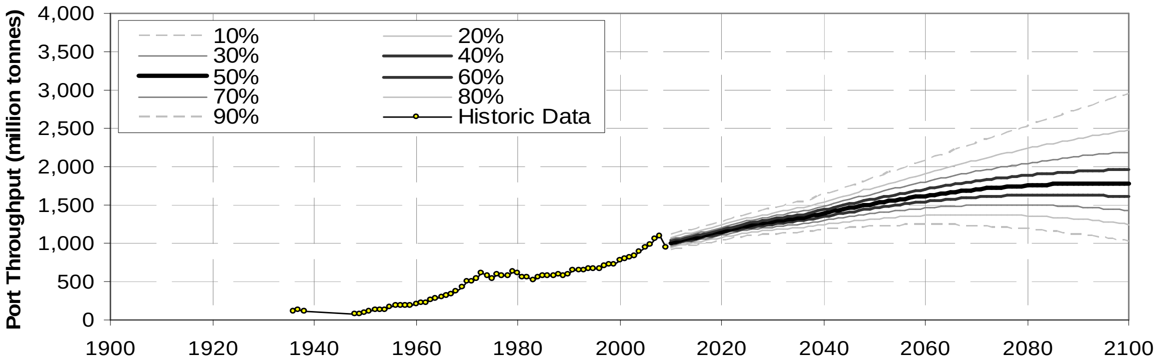
The forecast indicates that the GDP (and GDP per capita) growth will slow down over the next two decades as a result of the retirement of the baby boom generation. This effect cannot be fully compensated by an increase in labour productivity. After stabilisation of the labour outflow the GDP will further increase until the effect of total population decrease takes over.

5. Developing the Very Long Term Port Throughput Forecast

The final forecast is developed by applying the causal relation between GDP and port throughput. The estimate is based on a combination of the levels and differences approach.

5.1 Preparation of a very long term forecast based on a levels approach

The first (naïve) forecast of Equation 1 compares the levels of the GDP directly to the levels of the Port Throughput. In order to obtain the probabilistic forecast for each year 10,000 simulations were made with the Excel Add-on @Risk. For each simulation a GDP was drawn from the distribution function of the year under consideration. This value was then used in the stochastic causal relation between GDP and Port Throughput to obtain an estimate of the throughput volume of the ports. Finally the outcome statistics were summarized in order to derive the prediction intervals. The results are indicated in Figure 14.



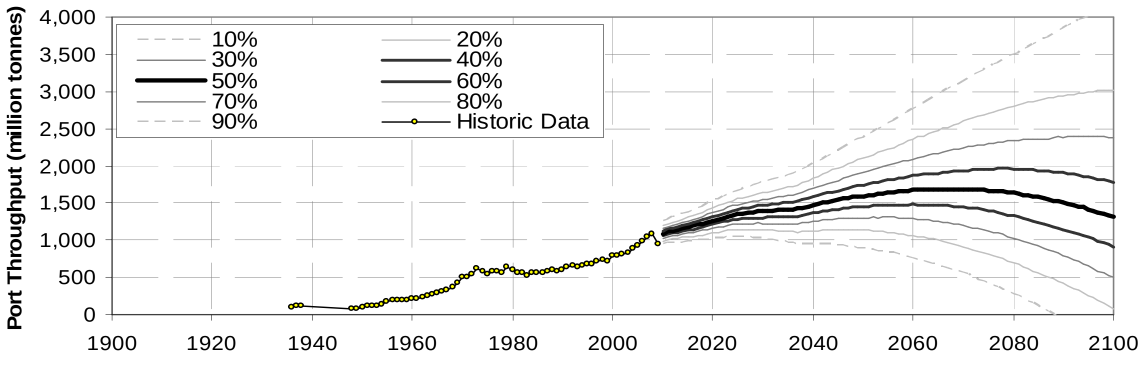
Source: Historic Data obtained from Port Authority of Antwerp (1936-2007) and Rotterdam (2008, 2009)

Figure 14. Naïve Forecast based on Levels Approach of Equation 1

Please note that the causal relation in the levels model is likely to be misspecified. Therefore the forecast is vulnerable to trend breaches, and has a prediction interval that is too small.

5.2 Preparation of a very long term forecast based on a differences approach

The forecast based on the differences approach of Equation 3 was derived using an almost similar methodology as discussed for the levels approach. The only difference is that the forecast starts in a certain base year and that for each following year the differences are calculated and added to the base year[18]. The results are indicated in Figure 15.



Source: Historic Data obtained from Port Authority of Antwerp (1936-2007) and Rotterdam (2008, 2009)

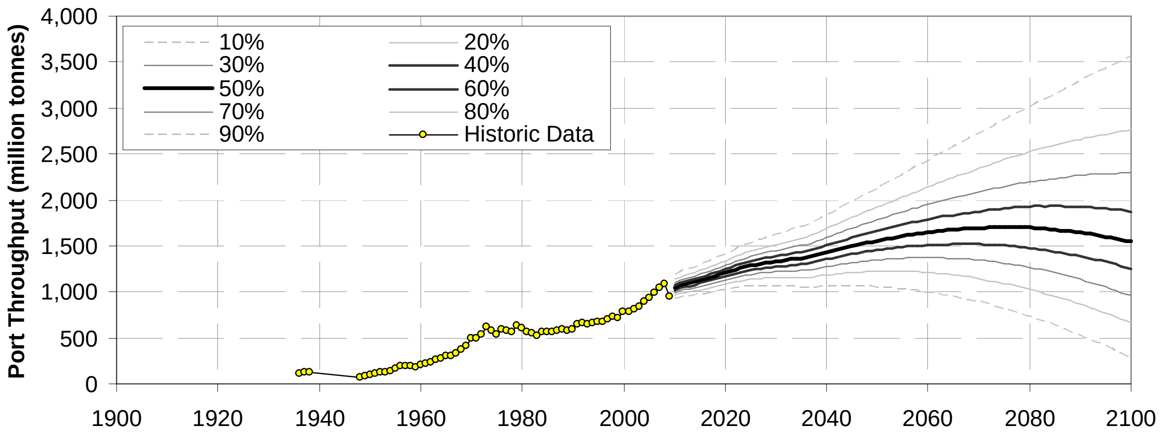
Figure 15. Single Forecast based on Differences Approach of Equation 5

[18] Due to the fact that the GDP estimate does not take into account economic cycles (it is based on future population and labour productivity assumptions) the choice of the base year is irrelevant. The use of the recession year 2009 as base year for the model resulted in a high forecasted GDP growth over 2010 which also implies a high throughput growth over 2010. The bandwidth shows that the throughput was at the level of the high 80% prediction interval in 2008 and dropped below the 10% interval in 2009 due to the recession.

The differences approach is statistically sound and therefore much more robust than the levels approach. However, on the long run Equation 3 represents the wrong model as the negative α coefficient forces the model downwards to a zero throughput after stabilisation of the GDP. Therefore the forecast can be expected to be increasingly downward biased as time passes. In addition to this the forecast ignores the fact that there will remain some common drivers (the ones that cause the risk for trend breaches in the levels approach) and therefore the variance estimate can be expected to be too conservative.

5.3 Final forecast based on a combined approach

Combining both forecasts is expected to reduce the bias in the mean and prediction intervals. The final forecast has been derived by taking the averages of both forecasts (refer Figure 16).



Source: Historic Data obtained from Port Authority of Antwerp (1936-2007) and Rotterdam (2008, 2009)

Figure 16. Final Forecast based on a Combined Levels and Differences Approach

From the forecast it can be concluded that the overall Port Throughput in the Le Havre – Hamburg range will likely increase by a factor 1½ - 2 up to 2080 after which it will slowly stabilize and finally decrease. The reduced pace of growth between 2010 and 2030 is caused by the mass retirement of the baby boom population. After 2030 the labour outflow stabilizes and both GDP and port throughput are expected to grow as a result of increased labour productivity. Finally from 2080 onwards the overall population decrease is expected to result in a stabilisation and decline of GDP and port throughput volumes.

5.4 Implication for port infrastructure planners

The notion of decreasing and stabilizing throughput volumes will help infrastructure planners to consider the (ultimate) capacity to be provided beyond the current expansion plans. In this respect it is important to realise that infrastructure development generally has a long lead time. For instance the development of the Second Maasvlakte took over 20 years. If future port infrastructure is considered to be developed for an economic lifetime of 50 years or more (which is not uncommon) this implies that it is necessary to look at least 70 years into the future when developing new plans. The notion of growth slowing down further implies that it will take longer before the capacity of new port infrastructure will be reached. This affects the economic feasibility and phasing of new port infrastructure projects.

6. Conclusions and Further Discussion

6.1 Conclusions

Literature pays almost no attention to port throughput forecasting and long term forecasting methodology. Nevertheless, a number of very long term studies on topics like population, energy, climate change and rise of sea water levels have been published over the past decades. Most of these studies point in the direction of scenarios. In some cases a balanced set of scenarios is developed on the basis of a probabilistic forecast. In our view this is an elegant way of developing scenarios for evaluation of policy alternatives. Therefore this paper presents a possible methodology for the development of a very long term probabilistic forecast of the port throughput in the Le Havre-Hamburg range up to 2100.

The applied methodology consists of three steps. In the first step a probabilistic forecast of the working age population is made on the basis of system dynamic modelling. The next step applies (expert) judgement to define (Bayesian) assumptions with respect to the development of labour participation, annual working hours, and GDP output per hour. On the basis of these assumptions the GDP forecast can be derived. Finally the port throughput forecast is obtained by applying the causal relation between GDP and port throughput. The discussion in this paper shows that it is possible to develop a probabilistic very long term forecast of the port throughput in the Le Havre – Hamburg range.

There are still a number of issues with respect to the reliability of the forecast. The main issues relate to the use of the causal relation between GDP and port throughput. Other issues relate to the fact that the Dutch GDP has been taken as a proxy for the development of the regional GDP; the fact that the population forecast has been compiled from various sources instead of being developed properly on the basis of a systems dynamic model; the fact that judgement has been required to define the assumptions on labour participation, working hours and output per hour; the fact that it is unclear if the year 2008-2009 should be regarded in as valuable information or an unwelcome outlier in the difference model of Equation 3; and the fact that by definition the unexpected event of a trend breach cannot be ruled out.

Despite many drawbacks, we still expect this forecast to provide a useful order of magnitude estimate of the throughput volumes in the Le Havre – Hamburg range. The fundamental message of this forecast is that we are no longer living in a world of exponential growth. Throughput volumes are likely to remain growing for quite a while but at a reduced pace. The central estimate indicates an increase of throughput by a factor 1½ - 2 up to 2080 after which it will stabilize and decrease. The wider confidence intervals indicate anything between a 30% drop and a 200% increase towards 2080. From 2080 onwards the prediction intervals grow larger indicating that it is difficult to extend our view further in time.

The notion of decreasing and stabilizing throughput volumes will help infrastructure planners to consider the (ultimate) capacity to be provided beyond the current expansion plans as well as the type of expansions that will suit future demand some 20 to 30 years from now.

6.2 Discussion

In 1697 a Dutch expedition led by explorer Willem de Vlamingh discovered a black swan on the Swan River in Western Australia. Until that moment the "*people in the Old World were convinced that all swans were white*" (Taleb, 2007, p.xvii). Unexpected events may change the course of time. Very long term forecasts are sensitive to trend breaches, foreseen or not (if not: Black Swans). However, on a high level of aggregation it can be expected that the risks of trend breaches are, to a certain extent, included in the variance of causal forecast relations. There is a trade-off between the forecast horizon and the level of detail that can be observed. It is not valid to predict the very long term development of a single detailed aspect (in our case, for example, the imports of certain chemical products through a specific port) but it may be possible to indicate a trend at an aggregated level (in our case, the total throughput in a larger port region). If details with respect to the individual ports, trade direction, or commodity need to be forecasted the valid forecast horizon will be considerably shorter.

The forecast presented in this paper is based on a simple one variable model that relates the port throughput to the GDP output of the region. This simple model was applied to avoid false reduction and to deal with the fact that adding additional explanatory variables also requires additional forecasts (or scenarios) of these variables to be made. If for some reasons one would like to improve the model by adding additional variables the most likely candidates would be *fuel prices*, *dematerialisation*, and *globalisation and regional trade patterns*. However, these issues are too detailed to be forecasted up to 2100. To deal with this problem various scenarios can be developed and the 'forecast' results can be presented as conditional probabilistic scenarios. The aim of this paper is however to present a single probabilistic forecast – not a set of scenarios with an uncertain likelihood.

It is reasonable to question the effect of structural changes to the major drivers addressed above. For example unprecedented high fuel prices may result in a reduction of global trade. We investigated the effect of high fuel prices on overall port throughput volumes by adding the historic price level of a barrel of oil as an additional variable in the forecast model[19]. Counter intuitive the regression statistics showed a significant *positive* relation which implies that a high oil price tends to correspond to a high throughput volume. This finding can be explained by considering the reversed causal relation. High global production, trade, and transport (reflected by high port throughput volumes) result in a strong demand for oil and consequently in high oil prices. In the past the effect of high oil prices on the overall port throughput volumes was rather small. Janssen et al. (2006, p.94) argue that according to various sources the structural effect of high oil prices on the level of the GDP and freight transport (including sea transport) is also almost negligible. In the future the structure of the freight transport system may however change as a result of scarcity of fossil fuels.

To some extent the effect of dematerialisation is already accounted for in the forecast by means of the constant negative α coefficient in the differences relation[20]. Further research is required to take the effects of dematerialisation properly into account in the forecast.

Since the end of the Second World War, the forces of globalisation have been acting towards world wide integration of many aspects in life including transportation of goods. It is not unlikely that this trend will enter a saturation phase in which growth of international trade due to further integration of economies will slow down. In addition some forces acting against globalisation may grow stronger and (partly) reverse the trend. It is unclear if globalisation is properly accounted for by the causal forecast relation, because the upward trend took place throughout the entire historic dataset.

This paper cannot be considered to provide a definite answer to the question raised. It rather provides a first attempt to develop an indication of the future throughput volumes up to 2100. Given the high level of uncertainties we think it is a challenge for future research to develop a wider view of the future on the basis of a larger framework in which a number of completely different methods are combined to explore the future. In this respect it may be promising to start with the development of a balanced set of conditional probabilistic scenarios to verify the robustness of the presented forecast method against completely different futures.

---

[19] Data was obtained from the BP Statistical Review of World Energy June 2010 in constant 2009 US$.
[20] See Section 3.3 for an explanation of the levels and differences approach.

Acknowledgements

The author thanks two reviewers for their valuable comments on the draft of this paper, and the Dutch Ministry of Infrastructure and the Environment (in particular Rijkswaterstaat) for its financial support of the research presented in the paper.

References

Alho, J.M. and Nikander, T. (2004). Uncertain Population of Europe Summary Results from a Stochastic Forecast'. Deliverable 12 belonging to *Work Package 6 of an EU 5th frame work funded research project Uncertain Population of Europe (UPE)*, HPSE-CT-2001-00095.

Armstrong, J.S. (1985). Long-Range Forecasting, From Crystal Ball to Computer, John Wiley & Sons, New York.

Armstrong, J.S. ed. (2001). *PRINCIPLES OF FORECASTING, A Handbook for Reaseracher and Practioners*, Kluwer Academic Publishers, Boston/Dordrecht/London.

Bails, D.G. and Peppers L.C. (1993). *Business Fluctuations: Forecasting Techniques and Applications*, Prentice Hall, Englewood Cliffs, New Jersey.

Bankes, S. (1993). Exploratory Modeling for Policy Analysis, *Operations Research*, Vol. 41, no. 4, pp. 435-449.

Bergheim, S. (2008). *Long-Run Growth Forecasting*, Springer-Verlag, Berlin Heidelberg, Germany.

Bowerman, B.L., O'Connell, R.T. and Koehler, A.B. (2005). *Forecasting, Time Series and Regression: An Applied Approach*, Thomson Brooks/Cole.

Charpentier S.R. (ed.) and Working Group for Millenium Ecosystems Assessment (2005). *Ecosystems and Human Well-being: Scenarios, Volume 2*, Islandpress, Washington, DC.

Chatau, B.N.Q. and the VLEEM consortium (2003). Assessment of the Very Long Term Development of the Needs for Energy Services: The VLEEM Methodology, *International Energy Workshop jointly organized by the Energy Modeling Forum (EMF)*, International Energy Agency (IEA) and IIASA. 24-26 June 2003 at IIASA Conference Center, Laxenburg, Austria.

Chen, S. and Chen, J. (2010). Forecast container throughputs at ports using genetic programming, *Expert Systems with Applications*, Vol. 37, no. 3, pp. 2054-2058.

Clements, M., Hendry, D. (1998). *Forecasting Economic Time Series*, Cambridge University Press.

DeLurgio, S.A. (1998). *Forecasting Principles and Applications*, Mcgraw-Hill College.

Diebold, F.X. (2004). *Elements of Forecasting*, Tomson South-Western, Canada.

Fildes, R. (1986). Editorial: Long-Term Forecasting and the Experts, *International Journal of Forecasting*, Vol. 2, no. 1, pp. 3-4.

Fildes, R. (2006). The forecasting journals and their contribution to forecasting research: Citation analysis and expert opinion, *International Journal of Forecasting*, Vol. 22, no. 3, pp. 415-432.

Fung, K. (2001). Competition between the ports of Hong Kong and Singapore: a structural vector error correction model to forecast the demand for container handling services, *Maritime Policy & Management*, Vol. 28, no. 1, pp. 3-22.

Goodess, C.M., All, J., Best, M., Betts, R., Cabantous, L., Jones, P.D., Kilsby, C.G., Pearman, A., and Wallace, C.J. (2007). Climate Scenarios and Decision Making under Uncertainty, *Built Environment*, Vol. 33, no. 1, pp. 10-30.

Granger, C.W.J. and Newbold, P. (1974). Spurious Regressions in Econometrics, *Journal of Econometrics*, Vol. 2, no. 2, pp. 111-120.

Guo, Z., Song, X. and Ye, J. (2005). A Verhulst model on time series error corrected for port throughput forecasting, *Journal of the Eastern Asian Society for Transportation Studies*, Vol. 6, pp. 881-891.

Hanke, J.E. and Wichern, D.W. (2008). *Business Forecasting*, Pearson/Prentice Hall, Upper Saddle River, New York.

Hui, E.C.M., Seabrooke, W. and Wong, G.K.C. (2004). Forecasting Cargo Throughput for the Port of Hong Kong: Error Correction Model Approach, *Journal of Urban Planning and Development*, Vol. 130, no. 4, pp. 195-203.

Heijer, F. den, Wolters, M.A., Dorsser, J.C.M. van, Berger, H.E.J. and Hijdra, A.C.L. (2010). Developing a substitution strategy for hydraulic structures to meet the challenges of a new century'. Paper presented at the *32nd PIANC Congress*, May 2010, Liverpool, UK.

Ickert, L., et al. (2007). Abschätzung der langfristigen Entwicklung des Güterverkehrs in Deutschland bis 2050, Progtrans, Basel.

IPPC (2007). *Climate Change 2007: Synthesis Report.* Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K., Reisinger, A. (eds.)]. IPPC, Geneva, Switzerland.

Janssen, L.H.J.M., Okker, V.R., and Schuur, J. (2006). *Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040,* Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau.

Jong, A. de (2008). Vier scenario's voor de zeer lange termijn, *Bevolkingstrends*, Quarter 4, Centraal Bureau voor de Statistiek.

Klein, A. (1996). Forecasting the Antwerp Maritime Traffic Flows Using Transformations and Intervention Models, *Journal of Forecasting*, Vol. 15, no. 5, pp. 395-412.

Levenbach, H. and Cleary, J.P. (2005). *Forecasting: Practice and Process for Demand Management*, Thomson Brooks/Cole, Belmont, CA.

Li, J., Chen, Y. and Cui, X. (2008). Port Throughput Forecast Based on Nonlinear Combination Method. Paper presented at the *7th WSEAS International Conference on APPLIED COMPUTER & APPLIED COMPUTATIONAL SCIENCE (ACACOS '08)*, April 2008, Hangzhou, China.

Lutz, W., Sanderson, W. and Scherbov, S. (2007). *IIASA's 2007 Probabilistic World Population Projections*, IIASA World Population Program Online Data Base of Results 2008, available from http://www.iiasa.ac.at/Research/POP/proj07/index.html?sb=5 (last access Nov.-2011).

Maddison, A. (2010). Statistics on World Population, GDP and Per Capita GDP, 1-2008 AD, *horizontal-file_02-2010.xls*, available from http://www.ggdc.net/maddison/ (last access Nov.-2011).

Makridakis, S., Wheelwright, S.C. and Hyndman, R.J. (1998). *FORECASTING, Methods and Applications*, John Wiley & Sons, Inc., USA.

Meadows, D.H., Meadows, D.L., Randers, J. and Behrens, W.W. (1972). *The Limits to Growth*, Universe Books, New York.

Meersman, H. and Van de Voorde, E. (2008). The Relationship between Economic Activity and Freight Transport, in Ben-Akiva, M., Meersman, H. and Van de Voorde, E. (ed) *Recent Developments in Transport Modelling, Lessons for the Freight Sector*, Emerald, UK.

Mentzer, J. and Bienstock, C. (1998). *Sales Forecasting Management*, Sage Pub, Thousand Oaks, CA.

Pindyck, R.S. and Rubinfeld, D.L. (1998). *Econometric Models and Economic Forecasts*, Irwin McGraw-Hill, Boston.

Policy Research Corporation (2007). *Beleidsstrategie Binnenvaart, Een landelijke markt- en capaciteitsanalyse*, Ministerie van Verkeer en Waterstaat, The Netherlands.

Schäfer, A., Heywood, J.B., Jacoby, H.D., and Waitz I.A. (2009). *Transportation in a Climate-Constrained World*, MIT Press Ltd.

Schwartz, P. (1996). *The Art of the Long View*, Currency and Doubleday, New York.

Taleb, N.N. (2007). The Black Swan, *The Impact of the Highly Improbable*, Penguin Books.

The Conference Board (2009). *Total Economy Database.xls*, http://www.conference-board.org/economics/database.cfm (last access in January 2009).

United Nations (1999). *The World at Six Billion*, ESA/P/WP.154, Population Division, Department of Economic and Social Affairs, United Nations Secretary, New York.

United Nations (2004). *World Population to 2300*, UN Department of Economic and Social Affairs, New York.

Veenstra, A.W. and Haralambides, H.E. (2001). Multivariate autoregressive models for forecasting seaborne trade flows, *Transportation Research Part E*, Vol. 37, no. 4, pp. 311-319.

Veerman, C.P. (2008). Samen werken met water: Een land dat leeft, bouwt aan zijn toekomst, Bevindingen van de Deltacommissie 2008, Deltacommissie, The Netherlands.

Vuuren, D.P., Vries, de B., Beusen, A. and Heuberger, P.S.C. (2008). Conditional probability estimates of 21st century greenhouse gas emissions based on the storylines of the IPCC-SRES scenarios, *Global Environmental Change*, Vol. 18, no. 4, pp. 635-654.

Weiqun C. and Nuo, W. (2003). Container thtoughput forecast model for a distict port based on bp neural network, *Proceedings of the Eastern Asia Society for Transportation Studies*, Vol. 4, pp.254-258. [Note: title contained errors in words throughput and distinct].

West, M., and Harrison, J. (1999). *Bayesian Forecasting and Dynamic Models*, Springer, New York.

Wilson, J.H., Keating, B. and John Galt Solutions Inc. (2009) *Business Forecasting with ForecastX*, McGraw-Hill/Irwin, Boston.