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Estimation of network level benefits of reliability improvements in intermodal freight transport

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ABSTRACT

An important problem in the assessment of reliability benefits of transport projects is that link level improvements must be translated to network level, so that they can be economically valued based on users' trips from origins to destinations. For intermodal transport, shipments follow a chain with more than one mode. Generally, this requires aggregation of travel time distributions that are not additive. We propose an approach that estimates the change in transport time reliability of an intermodal transport chain based on the changes for links of that chain. We demonstrate the framework of reliability assessment for a case study of network improvement for rail-truck intermodal transport in China. Also, we demonstrate the application in a cost-benefit analysis context with user valuations of transport reliabilities from the case at hand. The application leads to the result that projects for the renovation and expansion of the transshipment terminal perform better compared with project that improve rail haulage speed. Another finding is that the effect of reliability improvement projects can be super-additive at network level. In comparison with traditional methods, we conclude that the proposed method can better estimate transport time reliability benefits when the distribution of link travel times is highly skewed. Also, it opens new possibilities for further research for measuring correlated reliability measures within networks and for performing network resilience analysis.

1. Introduction

Reliability is one of the predominant performance measures in freight transport. To carriers, reliability is useful for planning, management, control, dispatching and marketing of single-mode and intermodal freight services (Fowkes, Firmin, Tweddle, & Whiteing, 2004). To shippers, reliability has been proved to be an important factor in deciding to use truck-only transport or intermodal transport (Winston, 1981; De Jong et al., 2014; Reis, 2014; Shams, Asgari, & Jin, 2017).

In truck-only transport, a major cause of unreliability is congestion on roads, including recurrent congestion around peak periods and delays because of incidents. In intermodal transport, shipments follow a chain of several modes and the causes of unreliability can be more diverse. Time fluctuation in different segment will contribute to the unreliability of the overall chain in different ways. Thus, analysis of the relationship between segments and the overall chain is of great significance.

Current approaches for evaluating reliability benefits of transport projects include two dimensions: estimating the changes in the reliability indexes and assessing the monetary value of that improvement

(Eddington, 2006; Halse, Samstad, Killi, Flügel, & Ramjerdi, 2010; Nicholson, 2015). As many projects only change the transport time characteristics (mean and/or standard deviation) of parts of a chain or network, an important problem in the assessment of reliability benefits of transport projects is that link level improvements have to be translated to network level, so that they can be economically valued on the basis of users' trips from origins to destinations. Since the intermodal transport chain consists of more than one mode, this requires aggregation of travel time distributions that are not additive. To this point, however, no clear approach has been put forward in the freight transport literature that allows to aggregate the reliability of link level transport times to the network level. In previous studies, a weak assumption, that all link level transport times followed the same distribution (usually normal or lognormal), was made to make them additive (for example, Richardson & Taylor, 1978; Tu, Van Lint, & Van Zuylen, 2007). Also, several studies applied simulation methods to solve this problem (Erfurth & Bendul, 2017; Robinson, 2004).

Our aim is to propose an approach that estimates the change in transport time reliability of an intermodal transport chain based on the changes for parts of chain. Although the Hasofer Lind-Rackwitz Fiessler

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(HL-RF) method we used in this paper has been known in the literature since 1978 (Rackwitz & Flessler, 1978), it is only of very recent times that applications for transport analysis have emerged, specifically for travel by private car (Yang, Malik, & Wu, 2014). We operationalize the approach here for intermodal freight transport chains and networks, to allow an analysis of the relationship between reliability of the overall chain and time distribution of every segment. We demonstrate the approach for a rail-truck transport chain in the hinterland of Yiwu-Ningbo port in China. We propose several reliability enhancing measures for the rail-truck transport operation and evaluate these measures by estimating changes in the market share ratio of rail-truck transport.

The rest of the paper is organized as follows. In section 2, we provide a review of the relevant literature on the issue of reliability in freight transport networks. In section 3, we introduce the approach to estimate the aggregate benefits of projects to improve transport time reliability. Section 4 and 5 covers the implementation and application of the proposed method. Section 5 concludes the paper with a summary of findings and recommendations for research and practice.

2. Literature review

As more and more companies adapt ‘just-in-time’ production methods, which involve reducing the costs associated with holding goods in stock, a reliable transport system is required so that cargo can be delivered promptly once ordered (Nicholson, 2015). The concept of reliability is usually defined as measures that relate to properties of the (day-to-day) transport time distribution, and particularly to the shape of this distribution (Bell & Cassir, 2000; Van Lint, Zuylen, & Tu, 2008). In the current literature, all studies use measures of transport time reliability based on one of the following four measures: (1) standard deviation, (2) spread, usually defined as the difference between percentiles, (3) percentage of shipments delayed or (4) average delay (Andersson, Berglund, Flodén, Persson, & Waidringer, 2017).

It is remarkable that the issue of reliability in freight transport has received some attention these years, but only little with respect to intermodal transport. Existing literature can be divided into two categories: (1) The first group focuses on the optimization of container terminals operation time (for example, Sgouridis, Makris, & Angelides, 2003; Rizzoli, Fornara, & Gambardella, 2002; Petering, 2009; Petering, 2011; Sergi & Enrique, 2011), (2) The second group investigates the effect of reliability on the transport mode choice, where intermodal transport service is considered as a portfolio of transport chain (for example, Wiegman, 2010; Feo, Espino, & García, 2011; Kim & Wee, 2011; Saeed, 2013; Reis, 2014).

Including benefits from reduction in transport time reliability in economic appraisals of transport project (i.e. Cost-Benefit Analysis, CBA) is important (De Jong et al., 2014). At present, methods to include the economic benefits of increasing transport time reliability within the economic appraisal procedure have been put forward in many countries, such as the United Kingdom (UK) (Eddington, 2006), Netherlands (De Jong et al., 2014), Norway (Halse et al., 2010), Sweden (Krüger & Vierth, 2015), Australia (Hensher, Puckett, & Rose, 2007) and the New Zealand (Transfund NZ, 2004). We are not aware of any publications in which network level reliability predictions, demand models and reliability valuations are applied in a consistent way. To the best of our knowledge, reliability prediction is not done at network level and/or cases of CBA involved different models for these elements.

Freight transport users are primarily interested in the benefits of reliability improvements for the complete transport chain, rather than for specific segments of the intermodal transport chain. However, many projects reduce the time variability of only parts of a chain, and require additional steps to estimate changes in the reliability of the intermodal transport chain, based on estimates of changes for parts of the chain. To conduct the relation between the reliability of the complete chain with variability of parts of a chain, UK practitioners estimate the change in standard deviation of trip times on urban roads (Department for

Transport, 2009) as follows:

$$\sigma_T = \sqrt{n} \sigma \quad (1)$$

Where σ_T is the standard deviation of complete trip times, n is the number of parts that the whole trip is split into and σ is the standard deviations for the parts. Equation (1) assumes that the standard deviations for the parts are equal and that travel times on the parts are independent. Nicholson (2015) discusses the correlation between the times of each part in a trip chain, and finds that ignoring this correlation can result in substantial errors in estimates of the benefits of projects. Also here, the hypothesis is made that the transport time of all the parts in a chain follow the same distribution (usually normal or log-normal). This is a rather weak assumption, however (Emam & Ai-Deek, 2006; Polus, 1979). Additional solutions are needed to calculate estimate the change in transport time reliability of an intermodal transport chain, based on the changes for parts of chain.

Building on earlier methods for reliability analysis (Hasofer & Lind, 1974; Rackwitz & Flessler, 1978) and inspired by a recent application for travel by private car (Yang et al., 2014), we introduce a method to calculate a reliability indicator at the network level for freight transport and demonstrate its application for intermodal freight networks. Compared to car networks, reliability analysis in intermodal freight transport is different in four aspects. First, in car networks, trips are split into several parts based on the type of road (i.e. highway or city road) or congestion conditions in the links, where the performance of links is strongly interdependent. As an intermodal transport chain combines modes and transfers between modes, the division along segments of the chain is easier and, arguably, more meaningful for strategic policy analysis. The second aspect is the complexity of the individual link travel time distributions, especially for access/egress trips to/from the trunk network. The uncertainty of demand and low frequency of the train or ship usually leads to a complex time distribution with multiple peaks and a long tail. Third, the translation of travel time distributions to service levels that can be offered is not trivial and requires a freight specific interpretation. Fourth, due to long legs and long transport time in an intermodal transport chain, the correlations between the transport time on individual legs are much weaker than the ones in a travel chain by private cars. This method assumes the transport times on the individual legs are independent with each other. To our knowledge, these issues have not been identified in the freight transport policy literature before.

In summary, we identify a number of research gaps and develop our contribution accordingly, as follows. We introduce an approach for network based reliability measurement for intermodal freight transport, which is new in the literature on freight transport networks, policies and cost-benefit analysis. Secondly, we demonstrate how this method can be applied in a real case for the assessment of benefits of a network improvement policy. Using a demand model, we consistently apply a network reliability prediction, reliability valuation and a prediction of choice of mode within the assessment. This is also a new approach in the literature.

The next section explains the methodology for network level reliability measurement.

3. Methodology

In this paper, we use “on-time delivery” as indicator to measure network level reliability. This indicator is widely used as it is close to freight decision makers’ practice (Shams et al., 2017). It measures reliability as the percentage of shipments arriving within the planned transport time (PTT), and can be expressed by probability (2).

$$R = Pr\{T \leq T_p\} \quad (2)$$

where R represents reliability of the transport chain, T represents actual transport time and T_p represents the PTT.

The method proposed here, to estimate the change in transport time

reliability of an intermodal transport chain is based on the HL-RF method. Its main characteristic is that it combines the First-Order Second-Moment (FOSM) algorithm to aggregate link reliability levels with the Equivalent Normalization method, to make distributions additive.

In engineering practice, the FOSM algorithm is generally used to compute the performance reliability index of a system. It is described by a function of statistically independent random variables (Hasofer & Lind, 1974) as the following function:

$$g(\mathbf{X}) = g(X_1, X_2, \dots, X_n) \quad (3)$$

where $\mathbf{X}$ is the vector representing components of the system, X_i ($i = 1, 2, 3 \dots n$) is a component in this system, and components are independent with each other. According to the value of function (3), three system states are classified: $g(\mathbf{X}) > 0$ means the system is in a safe state, $g(\mathbf{X}) < 0$ means the system is in a state of danger, and $g(\mathbf{X}) = 0$ is defined as a “limited state”. The reliability index β of the system is the minimum distance from the origin to a point on the limited state surface $g(\mathbf{X}) = 0$ and β can be calculated using the following nonlinear constrained optimization function (Yang et al., 2014):

$$\text{Object: } \beta = \min f(\mathbf{X}) = \min \sqrt{\mathbf{X}^T \mathbf{X}}$$

$$\text{Subject to: } g(\mathbf{X}) = 0 \quad (4)$$

where $f(\mathbf{X})$ is the distance from the origin to a point on the surface of $g(\mathbf{X}) = 0$.

In an intermodal transport system, $\mathbf{T}$ is the transport time vector and T_i ($i = 1, 2, 3 \dots n$) is the transport time of segment i in a chain. Time distributions are used to estimate the system performance function $g(\mathbf{T})$. Since the time of a transport chain is equal to the sum of all segments' time, $g(\mathbf{T})$ can be defined as follows:

$$g(\mathbf{T}) = T_p - \sum_{i=1}^n T_i \quad (5)$$

When the random variables are normalized to have zero mean and unit standard deviation, β is the variate of the standard normal Cumulative Distribution Function (CDF) at the most probable point of limited state for $g(\mathbf{T})$, which implies that the reliability of transport chain R defined by equation (3) can be obtained by the following equation:

$$R = \Phi(\beta) \quad (6)$$

where $\Phi()$ is the CDF of the standard normal distribution.

In the system performance function $g(\mathbf{T})$, random variable T_i ($i = 1, 2, 3 \dots n$) is intended to be normally distributed. Many variables, however, do not follow a normal distribution. A transformation of non-normal variables to equivalent normal variables is therefore proposed. Equivalent Normalization method (Rackwitz & Flessler, 1978) claims two requirements for the transformation of non-normal variables to equivalent normal variables: 1) the CDF of original and equivalent normal variables should be matched at the required point; 2) the Probability Density Functions (PDF) of both variables should also be matched. The conversion formula can be expressed as equations (7) and (8):

$$\sigma_i = \frac{\phi(\Phi^{-1}[F_i(t^*)])}{f_i(t^*)} \quad (7)$$

$$\mu_i = t^* - \Phi^{-1}[F_i(t^*)] \frac{\phi(\Phi^{-1}[F_i(t^*)])}{f_i(t^*)} \quad (8)$$

where μ_i is the mean value of equivalent normal distribution;

σ_i is the standard deviation of equivalent normal distribution;

t^* is the value of T_i in the design point;

$F_i(t^*)$ is CDF of the original distribution;

$f_i(t^*)$ is PDF of the original distribution;

$\Phi(t^*)$ is CDF of standard normal distribution;

$\phi(t^*)$ is PDF of standard normal distribution;

Using the HL-RF method to compute reliability index β , the reliability of transport chain R can be estimated as equation (9) (Yang et al., 2014):

$$R = \Phi(\beta) = \Phi\left(\frac{T_p - \sum_{i=1}^n \mu_i}{\sqrt{\sum_{i=1}^n \sigma_i^2}}\right) \quad (9)$$

It can be seen that transport time reliability of the chain is a function of the mean and standard deviation of the transport times for the parts of the chain. As a result, the change in transport time reliability of an intermodal transport chain based on the changes for parts of chain can be estimated.

4. Application

4.1. Introduction

Our demonstration concerns rail-truck container transport chain in China, in terms of a transport from Yiwu Port (a dry port in the Yiwu region) to the Ningbo Beilun wharf at the Beilun maritime port. The overall chain consists of three segments, as shown in Fig. 1. Segment 1 starts from where the shipment is picked up by the truck at Yiwu Port, and ends with the shipment being loaded on the train at West Yiwu Station (a rail station in Yiwu). Segment 2 starts from the train at West Yiwu Station and ends at Beilun Station, a rail station in Ningbo. Segment 3, a trucking link, starts from the Beilun rail terminal and ends with the delivery at the Beilun wharf.

At present, there is no information system that tracks the rail-truck transport chain from door to door. This makes it difficult for us to collect times of all the three segments for a container transported by rail-truck. As a result, we sample at random in three segments, respectively. We collect the times of segment 1 for 164 containers from the truck carriers, who are responsible for the drayage from Yiwu Port to West Yiwu Station. Rail operator of West Yiwu Station provides the times of segment 2. Totally, the departure and arrival times of 120 freight trains are obtained. The times of segment 3, for 242 containers, are collected from the truck carrier in the Beilun port. Table 1 summarizes the transport time distribution observations. Note that, due to data limitations, container dwell time at the terminals was included in the truck drayage times to and from the terminal.

The area of the rail freight yard is small and the handling equipment in the rail freight yard is outdated. This often causes long waiting times for container trucks. As a result, the transport times of both Segment 1 and Segment 3 are long.

4.2. Transport time distribution

The first step of the application is to analyze the transport time distributions of the segment in the chain. The Kernel Density Curve of the transport time in every segment is determined and results are shown in Fig. 2. Based on the Kernel Density Curve, four commonly used probability density distributions including normal distribution, log-normal distribution, gamma distribution and Weibull distribution are applied for curve fitting analysis.

We used a log-likelihood estimator to determine the best fit. The results, summarized in Table 2, indicate that the lognormal distribution is the best curve fitting for T_1 and the normal distribution is better for T_2 and T_3 .

We performed an additional Kolmogorov-Smirnov (K-S) test for these three distributions. The p-values of K-S test are all larger than 0.05. This confirmed that the null hypotheses, which T_2 and T_3 are consistent with a normal distribution and T_1 is consistent with a log-normal distribution, are all accepted under the significance level of 0.05. The p-values of K-S test and parameters estimated are shown in Table 3.

Fig. 1. Study corridor geography.

Table 1
Summary of the data for every segment.

Statistics	T_1/h	T_2/h	T_3/h
Sample Size	164	120	242
Mean	10.33	6.67	16.59
Std Deviation	7.04	0.69	11.87
Skewness	2.14	−0.23	−0.21
Kurtosis	4.29	−1.27	−1.96
Minimum	1.70	5.52	1.90
Maximum	37.22	7.80	28.92

Note: T_1 , T_2 , T_3 represents the time of Segment 1, Segment 2, and Segment 3, respectively.

4.3. Changes of transport time characteristics

At this moment, the market share ratio of rail-truck container transport is very low, accounting for about 0.6%. Truck-only is the most used transport mode on this corridor today. The government, rail operators and Ningbo Port Group plan to take measures to improve the market competitiveness of rail-truck transport. Based on the field research with the rail operators in West Yiwu Station, measures that have been put forward and the expected changes for the transport time characteristics are listed as follows:

- Measure (1) is to establish a customs area in West Yiwu Station, and to improve train departure time alignment with customs working time, which can lead to a reduction of both the mean and standard deviation of T_1 by 2 h.

Fig. 2. Fitting results for the time of every segment.

Table 2
Log likelihood estimator of fitting results.

Distribution	Log likelihood		
	T_1	T_2	T_3
Lognormal	–683.406	–26.883	–97.920
Normal	–771.466	–26.058	–97.339
Weibull	–719.851	–26.131	–98.017
Gamma	–700.972	–26.740	–97.927

Table 3
Results of the K-S test and parameters estimated.

Variable	Distribution	P-value	μ	Std. Err.	σ	Std. Err
T_1	Lognormal	0.057	2.20	0.04	0.28	0.03
T_2	Normal	0.427	7.53	0.13	0.68	0.10
T_3	Normal	0.111	15.36	0.92	13.49	0.65

- Measure (2) is the renovation and expansion of Beilun Station. Due to the small area and the old handling facilities, container trucks usually wait for a long time at the rail yard in Beilun Station. Both the mean and standard deviation of T_3 will reduce by 2 h after the renovation and expansion.
- Measure (3) is to improve the rail service via upgrading the speed of the train from 80 km/h to 120 km/h, which may lead to the mean of T_2 reducing by 2 h. However, the standard deviation of T_2 will not change.
- Measure (4) combines the above measures (1) to (3).

4.4. Reliability at chain level and new service offering

The HL-RF method mentioned above is used to estimates the change in transport time reliability of the intermodal transport chain, based on the original distribution of transport time in each segment and changes of transport time characteristics result from proposed measures. Fig. 3 shows the transport time reliability calculated before/after taking these measures for this rail-truck transport chain, when the PTT is factored in.

From this point, the new reliability measures at intermodal chain level need translation into service level offerings that can be used for impact assessment. Three important indicators including the 90th percentile transport time, the mean of transport time of the chain and the

Table 4
Indicators of transport time under different scenarios.

Scenarios	90 th percentile/h	Mean/h	Buffer time/h
Original situation	51.5	31.4	20.1
Customs area	49.1	30.0	19.1
Station expansion	47.4	29.4	18.0
Rail line upgrade	49.5	29.4	20.1
Combined measures	42.8	26.0	16.8

buffer time are discussed. Buffer time is defined as the additional transport time in advance to make sure that the probability is large enough (90% is considered in this paper) for the carrier to reach the destination within the time requirement. These three indicators for different scenarios are listed in Table 4.

As shown in Table 4, the 90th percentile transport time is 51.5 h at present, which means that the rail-truck operator can promise that containers will be delivered to the Beilun Wharf within 51.5 h with a 90% probability. We assume 51.5 h which will lead to a 90% reliability in the original situation as a PTT. Without considering measure (4), measure (1) increases the reliability to 91.6% at a given PTT of 51.5 h, while measure (2) and measure (3) raise it to 93% and 91.5%, respectively. The corresponding benefit on transport time reliability is 1.6%, 3.0% and 1.5%, respectively for measure (1), measure (2), and measure (3).

Furthermore, measure (2) decreases the mean of transport time from 31.4 h to 29.4 h, so that the buffer time is decreased to 18 h. Comparing measure (1) with measure (3), they decrease almost the same 90th percentile transport time (49.1 h and 49.5 h). However, the mean of transport time at measure (3) situation is smaller than measure (1) situation (29.4 h and 30 h), which results in a larger buffer time at measure (3) situation (20.1 h).

In general, measure (2), which is renovation and expansion of Beilun Station, performs best for establishing a reliable rail-truck transport chain, followed by measure (1), and measure (3). Combing these three measures (denoted as measure (4)) increases the reliability by 7.0% at a given PTT of 51.5 h, which is larger than the sum of reliability increased by measure (1), (2) and (3) (1.6% + 3.0% + 1.5% = 6.1%). Alternatively, measure (4) decrease the buffer time to 16.8 h. This super-additivity of reliability improvements with an additional effect of almost 15% is an interesting finding.

Intermodal transport chain consists of more than one element. Main

Fig. 3. Reliability of the chain at a given PPT.

Fig. 4. The results of increased reliability comparisons.

causes of unreliability are more likely to occur at the connection between modes. Especially in the case of low frequency (1 departure per day in this case), a delay of 1 h in the first part of the chain may mean that a connection is missed and the delay jumps to 24 h. Vice versa, if the entire system is effectively connected, the reliability improves sharply. From this point, we should understand why super-additivity of reliability improvements exists.

Due to the combined impact of diverse shapes of the starting distributions and the specific allocation of policy measures, it is difficult to predict how reliability improvements will add up. The approach described herein, however, does illustrate the possibility to identify such advanced network effects of reliability improvements.

4.5. Comparisons of transport time reliability estimation methods

As mentioned in the introduction, two methods are used in the existing literature: (1) the first one assumes that transport times of all the parts in a chain follow the normal or lognormal distribution to ensure them to be additive, (2) the second one adopts a simulation method. To evaluate our method we also apply these two existing methods, using the same dataset, to compute the impacts of the different measures. For method (2), we implemented a routine in MATLAB to draw at random from the distributions of the three legs and create a total distribution. The number of draws is set at 1000. The result of comparison is demonstrated in Fig. 4.

The figure shows that the transport time reliability calculated from the method (1) is found to be larger than the one calculated from both the proposed method and the method (2), especially for measure (1). This is because the method (1) considers T_1 following normal distribution, which reduces the dispersion degree of transport time of the chain. The proposed method captures the real shapes of the starting distributions by HL-RF algorithm. Therefore, the proposed method can better assess the effects of reliability enhancing measures.

5. Demand impacts of improved services

In this section, we evaluate the effects of improvements of reliability by estimating changes in the market share of rail-truck transport. As demand model, we use a logit model, which builds on discrete choice, random utility theory. The data used in this research are obtained by means of a Stated Preference (SP) experiment and we use an error components model (Train, 2009).

Personalized face-to-face interviews were conducted in September 2014. The survey covered 25 firms in the Yiwu area among both freight

forwarders and shipper companies. A questionnaire, which was structured into three parts, was distributed.

- The first part was designed to obtain general information about characteristics of the company, numbers of employee, numbers of truck, etc. included.
- In the second part, the interviewers were asked to recall a recent shipment in this corridor and gathered information regarding their primary characteristics, including the cargo value, shipment size, the mode used, characteristics (cost, time, reliability) of this mode and the optional mode.
- In the third part, we conducted a SP experiment to collect data about the decision-makers choices to understand their preferences.

The SP experiment offers two alternatives, truck-only transport and rail-truck transport. Attributes including time, cost and reliability are taken into consideration for both alternatives (shown as Table 5). According to the inquiry with freight forwarders before this survey, the average cost, time and reliability for truck-only transport were 2400 RMB (per high cube container), 18 h, and 80%, respectively. The average cost, time and reliability for rail-truck were 2300 RMB (per high cube), 31 h, and 90%, respectively. These were set as the present level for choice situations in the SP experiment. Also, they were used to estimate the market share, as described in the following section. The number of levels for each attribute considered is restricted to 3 and an orthogonal fractional factorial design is used to reduce the number of scenarios in order to avoid interviewees having to consider too many options. Fig. 5 provides an example of scenarios created for this survey.

Based on the 375 SP observations collected, the software NLOGIT was used to estimate parameters of the model. We firstly use a simple

Table 5
Attributes and levels considered in the SP experiment.

Mode	Truck-only			Rail-truck		
	Cost	Time	Reliability	Cost	Time	Reliability
Unit	RMB/HQ	Hours	%	RMB/HQ	Hours	%
Level 1	Present	Present	Present	Present	Present	Present
Level 2	105%	95%	85	80%	85%	90
Level 3	110%	105%	90	90%	90%	95

Note: Level 2 and Level 3 noted as % of Level 1; Reliability noted as expected performance.

Base on the shipment you provided above, supposing that all other attributes are invariant except for cost, time and reliability of both two modes, please choose a mode of transportation for this shipment again.

Scenario1	Mode	Cost (RMB/HQ)	time (Hours)	Reliability (%)	Your Choice
	Truck-only	2400	18	80	☐
	Rail-truck	2300	25	90	☐

Fig. 5. An example of SP scenarios.

model as basis in which only the variables defined in the SP experiment are considered, and other specifications that include variables such as shippers related attributes (i.e. numbers of employee, numbers of truck) or shipment related attributes (i.e. value of shipment, shipment size) are then tested. The best model found is specified as follows:

$$U_{truck} = \beta_c C_{truck} + \beta_t T_{truck} + \beta_r R_{truck} + ASC + \mu + \varepsilon_{truck} \quad (10)$$

$$U_{intermodal} = \beta_c C_{intermodal} + \beta_t T_{intermodal} + \beta_r R_{intermodal} + \varepsilon_{intermodal} \quad (11)$$

Where U_{truck} , $U_{intermodal}$ represents the utility functions of truck-only transport and rail-truck transport, respectively. C , T and R represent the attributes cost, time and reliability, respectively. ε is a stochastic component for unobservable effects. ASC is the specific constant of truck-only alternative, and β is the parameter of attributes. μ is an additional vector of random errors, independently normally distributed with mean zero and standard deviation σ , which allows to capture the correlation between the choices made by one same individual. The high statistical significance of the variable σ confirms that the error components model is more suitable than standard logit model. A model of which the specification is the same as equations (10) and (11), but the coefficients β are considered as random coefficients with a normal density function, was also estimated. The standard deviations obtained for these coefficients were not significant. Therefore, in this case, no random variation in preferences was found, which may due to the low number of respondents. In follow-up research, we would suggest to use an efficient design for the SP surveys to improve the statistical performance of the model. The results obtained after estimating the model being considered are shown in Table 6.

As shown in Table 6, the McFadden determination coefficient Rho^2 (0) is 0.575, which indicates this model is good at explaining freight mode choice behavior. In addition, the high statistical significance of the σ confirms the error components model is more suitable than the standard logit model.

Thus, we use the model to estimate market share ratio of rail-truck transport under different reliability enhancing measures. Table 7 shows

Table 6
Parameter estimation results.

Variable	Parameter	Estimate	T-test
Truck-only alternative specific constant	ASC	3.594	0.70
Cost	β_c	-0.004***	-6.51
Time	β_t	-0.152***	-4.43
Reliability	β_r	0.012*	1.81
Statistical indicator	Sigma σ	1.271***	6.20
	Observations	375	
	Log(L)	-104.390	
	$Rho^2(0)$	0.575	

Note: *, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively.

Table 7
Attributes value of rail-truck transport under different measures.

Attribute	Present situation	Enhancing measures			
		(1)	(2)	(3)	(4)
Cost/RMB per HQ	2300	2300	2300	2300	2300
Time/h	31	30	29	29	26
Reliability/%	90	92	93	92	97

Table 8
Market share of intermodal transport.

Scenario	Intermodal share
Original situation	0.6%
Customs area	0.7%
Station expansion	0.8%
Rail line upgrade	0.7%
Combined measures	1.4%

the attributes value of rail-truck transport before/after these measures are put forward.

The simulation results are shown in Table 8. The results indicate that measure (2) increases the market share by 33% (0.2%/0.6% = 33%). Measure (1) and (3) only increase the volume by 16.7% (0.1%/0.6% = 16.7%). Combining these three measures will increase the volume of rail-truck containers transport in this corridor by 133% (0.8%/0.6% = 133%). Again, we find that combining the improvement measures has an effect which is larger than the sum of individual effects.

In our specific case, the market share of rail-truck transport remains much lower than the share of truck-only. This is mostly because the cost of rail-truck transport (2300 RMB per High cube) is only slightly lower than truck-only transport (2400 RMB per High cube), while a large gap of transport time exists between them (18 h for truck-only transport). Therefore, other measures remain necessary to improve the competitiveness of intermodal transport. Regardless of the absolute numbers, the main purpose of the section was to demonstrate the application of the reliability measurement approach in the context of benefit assessment of improvement policies.

6. Conclusion

This paper presents a method for the network level assessment of transport reliability improvements. This method allows to estimate the change in transport time reliability of an intermodal transport chain based on the changes for parts of chain, using the HL-RF method combining the FOSM algorithm with Equivalent Normalization.

The method was applied in a reliability assessment for a case

concerning rail-truck container transport in China. Segment level reliability measurements are done and normalized to allow aggregation. Individual measures for reliability improvement on segments of the intermodal chain are aggregated to origin-destination level. Given the aggregate reliability improvements, we translate the new reliability measures to service levels for intermodal movements. Next the impact of the service level improvements is assessed using a demand model that was developed using a custom SP survey and choice model. The results of the application show that impacts of individual projects are super-additive, both in terms of the possible service offering at chain level, as well as in terms of the effects on modal shift. Amongst the alternative measures, we find that intermodal railyard improvements produce a more reliable rail-truck transport chain compared with speed increases on the trunk line.

In comparison with the assessment result using traditional methods, we demonstrate that the real shapes of transport time distributions on links should be considered. Failing to consider it will cause bias in the estimation of benefits on transport time reliability, especially for highly skewed distributions.

The approach proposed in this paper may also advance network reliability evaluation in practice. It may provide support for transport planners or intermodal operators to evaluate door-to-door impact of reliability improvement measures or to better identify the critical parts of the network that improvement measures should focus on.

Extensions of the methods may lie in the consideration of dependencies between reliability indicators as discussed in (Nicholson, 2015). In addition, our illustration was limited to a simple transport chain. However, network level metrics also allow applications at network level, for example refining approaches for measuring and optimizing network resilience (Wan, Yang, Zhang, Yan, & Fan, 2017; Zhang, Mahadevan, Sankararaman, & Goebel, 2018).

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