Impact Assessment Model of International Transportation Infrastructure Development: Focusing on Trade and Freight Traffic in Central Asia

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Abstract: This paper analyzes the expected impacts of improved border-crossing services on international freight transportation in Central Asia (CA). It develops a freight traffic network-assignment model based on the user equilibrium principle, and the developed model is combined with a global general equilibrium model to analyze the impacts of infrastructure development on regional economy and trade. Three cases are simulated to assess the improved border-crossing services. The results show that improvements in border-crossing service provision significantly decrease international transportation costs and boost trade flows in and out of CA in the short run. However, further growth of regional trade causes traffic congestion, which leads to an increase in international transportation costs, potentially reducing long-run trade volumes to and from CA. The analysis thus suggests that further improvement of CA transportation services is a prerequisite for the sustainable growth of regional trade.

Keywords: Cross-border freight traffic, traffic assignment, Central Asia

1. INTRODUCTION

Since the dissolution of the Soviet Union in 1991, the landlocked countries of Central Asia (CA), namely, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, have become largely isolated from international markets. The World Bank (2009) argued that poor infrastructure results in high transportation costs for landlocked countries, negatively affecting their trade relationships. One way to overcome these market barriers would be to develop a regional transportation network among the CA countries. Although the transportation network was originally designed to support the planned Soviet economy, it has been poorly renovated and should now be integrated into the global transportation network. The Central Asia Regional Economic Cooperation (CAREC) Program, led by the Asian Development Bank, has been promoting regional cooperation and development in CA since the late twentieth century. From 2001 to 2013, the program invested US$22.4 billion in regional infrastructure and initiatives to promote connectivity and trade, which helped the landlocked countries to reach the global market. From 2001 to 2013, almost US$18 billion was invested in 98 CAREC-related road projects along the six CAREC corridor routes (ADB, 2013b). However, the impacts of these CAREC transportation infrastructure projects on the economy and trade have not been analyzed.
from regional perspectives, largely due to difficulties in data collection and poor data reliability. Insufficient data has made it difficult to evaluate the impact of these projects and to handle priorities for infrastructure projects from regional perspectives. This study, however, overcomes the problem of poor data availability in CA by utilizing a new integrated dataset that was created by the authors’ team (Tanaka et al., 2014). This paper aims to develop a model for analyzing the economic impact of transportation infrastructure projects on freight transportation costs and international trade. This is done by following the methods proposed by Iwata et al. (2011, 2012) and Shibasaki and Watanabe (2012).

The rest of this paper is organized as follows. The following section summarizes the extant research related to the impact analysis of transportation infrastructure development in CA, after which the model developed to analyze interregional traffic flows in transportation networks is presented. Subsequently, the developed model is combined with a global general equilibrium model. Finally, the results of the study are summarized and further research issues are presented.

2. LITERATURE REVIEW

Although many prior studies have shown the importance of transportation infrastructure in CA (George, 2012; Elena, 2012; Kurmanalieva and Parpiev, 2008; Maeno, 2012; Mizohid et al., 2005; Pomfret, 2010; Roman, 2012), few studies have focused on the regional impact of transportation infrastructure development. Arvis (2010) highlighted the complexity of supply chains to and from landlocked developing countries and proposed a supply chain framework that allowed for an understanding of logistics cost structures. Corridor Performance Measurement and Monitoring (CPMM) (CAREC, 2011, 2012) collected information relating to transportation time and cost for each road and railway section and border-crossing point (BCP) from local freight forwarders. The International Road Transport Union (2011) analyzed cargo flows in CA and the border regions of the People’s Republic of China (PRC) from the viewpoint of freight forwarders and provided a dataset of the traffic volume by each transportation mode and transportation cost mainly collected from freight forwarders. Rastogi and Arvis (2014) examined in detail the bottleneck of regional trade supply chains in a CA region adjacent to emerging economies and located at the center of the Eurasian continent.

Rastogi and Arvis (2014) also pointed out that two recent developments were likely to encourage significant changes in regional trade and traffic in CA. First is the implementation of the Eurasian Customs Union (ECU), which includes Belarus, Kazakhstan, Russia, and Kyrgyzstan. Since customs control of borders between the Union members has been phased out, the Union has a direct facilitation impact on regional trade. Kazakhstan entered into the ECU with Belarus and Russia in 2010, whereas Kyrgyzstan joined the Union in 2014. World Bank (2012) developed a 57-sector modern computable general equilibrium model of Kazakhstan to assess the impacts of these policy changes using scenarios constructed by Shepotylo (2011). Kyrgyzstan’s accession to the ECU in 2014 has been expected to change the regional freight traffic flow structure. ADB made the following assumption about the change: (1) the entry of Kyrgyzstan into the ECU and adoption of the ECU tariff will unblock the borders among Customs Union members, but at the same time will eliminate massive cost arbitrage for the re-export of consumer goods via Dordoi, which has played an important role in the development of Kyrgyzstan’s apparel sector and still plays an important role as an essential element of the sales and distribution chain for this sector; (2) there is no obvious answer, about what will happen with Dordoi and the Kyrgyzstan–Chinese transportation corridor. Thus, more detailed analysis of potential impacts of Kyrgyzstan’s accession to the ECU may be required. A key
The second major development mentioned by Rastogi and Arvis (2014) is the strong interest of the government of PRC in developing and facilitating overland trade with CA. Major rail infrastructure is being completed to increase the capacity toward Kazakhstan and the Kyrgyz Republic. Special zones are being created at borders such as at Khorgos (Xinjiang Province in PRC and Kazakhstan). Meanwhile, severe cargo congestion has occurred on the Alashankou–Dostyk railway BCP due to differences in the rail track gauges between PRC and the Former Soviet Union (Jetro, 2013) and because of the huge expansion in trade to and from PRC (Johannes, 2012).

Although these studies described the current regional infrastructure conditions, reported traffic flow patterns, and identified specific issues, they did not analyze the impact of transportation infrastructure projects and trade facilitation improvements on traffic flow in CA. In practice, the Highway Development and Management Model (HDM-4), which was originally developed for the evaluation of road investment, has been widely used for the economic analysis of infrastructure projects. This model enables us to estimate the expected reduction in vehicle operating costs and transportation time by inputting data such as the observed traffic volumes by vehicle type and International Roughness Index (IRI) of projected roads. The input data used in the HDM-4 is typically collected by local consultants with support from the local governments (Rodrigo, 2008). The benefit of the projects is estimated by computing the total cost savings of road users, including the estimated reduction of transportation time and vehicle operating costs. However, the HDM-4 cannot estimate the indirect impacts of transportation projects such as the change in GDP and/or regional trades, although it can estimate the direct impacts. This means that the impacts of infrastructure projects on international cargo flows and regional trade cannot be analyzed with the HDM-4.

To the best of our knowledge, no study has successfully shown the regional impacts of transportation infrastructure development on economy, trade, and international traffic flows in CA. This is mainly due to poor data availability and low data reliability in the region. It should be noted that partial statistical data of international cargo volumes could be obtained from the customs records in each country; however, it often contains wrong and/or biased information (Tanaka et al., 2014). The quality of railway traffic data in particular is poorer than that of road traffic data because railway transportation requires more stakeholders to build the database than road traffic does (ADB, 2013c).

3. MODEL DEVELOPMENT

3.1 Model Structure

In this study, the potential impacts that improvements in transportation infrastructure in CA could have on regional economy and traffic flow patterns will be analyzed using the Global Trade Analysis Project (GTAP) model and the Multimodal International Cargo Simulation model for Central Asia (MICS-CA) developed by the authors. The MICS-CA enables us to analyze the impact of infrastructure development on transportation cost and traffic volume in a land shipping network by using the user equilibrium (UE) assignment approach. The GTAP model enables us to forecast the impact that change in trade cost and expected economic development would have on bilateral trade volumes and regional economies by using the spatial computable general equilibrium model, which covers multiple sectors in multiple regions, with the assumptions of perfect competition and constant returns to scale (Hertel and Tsigas, 1997). This study highlights an integrated approach incorporating traffic analysis with economic
impact analysis to estimate the indirect impacts of transportation infrastructure projects, which has not been analyzed quantitatively with the existing analytical models. Figure 1 illustrates the computation process using the two models.

![Computation Process using GTAP and MICS-CA](image)

### 3.2 Application of GTAP Model

In this study, the GTAP model is used for estimating the impact of changes in trade cost on bilateral trade and the economy. The impact of trade cost changes on the economy and trade demand with the GTAP model was estimated using the method developed by Kadono et al. (2005). The GTAP model formulates the trade flows from one region to another region when the transportation service is changed as:

\[
QTMFSD^* (i,r,s,m) = \left[1 + atmfsd (i,r,s,m)\right] \cdot QTMFSD (i,r,s,m)
\]  

where

- \(QTMFSD^* (i,r,s,m)\) : quantity of commodity or service \(i\) from region \(r\) to region \(s\) by transportation mode \(m\) when the transportation service is changed,
- \(atmfsd (i,r,s,m)\) : technical change coefficient on transportation of commodity or service \(i\) from region \(r\) to region \(s\) by transportation mode \(m\), and
- \(QTMFSD (i,r,s,m)\) : original quantity of commodity or service \(i\) from region \(r\) to region \(s\) by transportation mode \(m\).

The variable “atmfsd” in the GTAP model, which signifies a change in transportation technique, is increased by \(100X/(100–X)\)% when the trade cost is reduced by \(X\)%.

For example, “atmfsd” is assumed to increase by 50% when the trade cost is reduced by 33.3%.

### 3.3 Estimation of MICS-CA
The impacts that the improvement in transportation infrastructure in CA would have on
interregional traffic-flow patterns are analyzed using the MICS-CA. The MICS-CA, which was
developed by extending and improving an existing model proposed by Shibasaki et al. (2005),
analyzes multimodal international freight flows. Using an origin–destination (O-D) matrix of
cargo flow volume, the MICS-CA outputs traffic flows and transportation costs. The existing
MICS, which mainly focuses on the maritime container shipping network, applies a simple
stochastic network assignment approach to a shipper submodel that assigns cargoes to the
intermodal transportation network (including maritime and land shipping) without considering
traffic congestion. However, the MICS-CA developed in this paper mainly focuses on the land
shipping network, and hence, it incorporates two types of traffic congestion by using the user
equilibrium (UE) assignment approach.

The UE problem is formulated as:

\[
\min_x z(x) = \sum_{a \in A} \int_0^{x_a} G_a(x) \, dx
\]

subject to

\[
x_a = \sum_{(r,s) \in O \times D} \sum_{k \in K_{rs}} \delta_{a,k} \cdot f^r_k \quad \text{for} \quad \forall a
\]

\[
\sum_{k \in K_{rs}} f^r_k - q_{rs} = 0 \quad \text{for} \quad \forall r, s
\]

\[
f^r_k \geq 0 \quad \text{for} \quad \forall k, r, s
\]

where

\begin{align*}
z(x) & : \text{an objective function}, \\
a & : \text{a link}, \\
A & : \text{a set of links}, \\
x_a & : \text{traffic flow of link } a, \\
G_a(\cdot) & : \text{cost function of link } a, \\
r & : \text{an origin}, \\
s & : \text{a destination}, \\
O & : \text{a set of origins}, \\
D & : \text{a set of destinations}, \\
k & : \text{a path}, \\
K_{rs} & : \text{a set of paths for the O-D pair } rs, \\
\delta_{a,k} & : \text{Kronecker delta, which is equal to 1 if link } a \text{ belongs to path } k \text{ for O-D pair } rs, \text{ and 0 otherwise}, \\
f^r_k & : \text{traffic flow on path } k \text{ for O-D pair } rs, \text{ and} \\
q_{rs} & : \text{cargo shipping demand from } r \text{ to } s.
\end{align*}

The congestion incorporated into the MICS-CA is congestion at national borders. Long
lines of trucks are often observed at national borders in CA; truck drivers must wait for up to a
week at borders, according to the CPMM report (CAREC, 2011, 2012). Also, trains must wait
for customs clearance procedures at railway BCPs. The processing time that causes this border
congestion might be a function of the transit demand (traffic volume), the time required for the
finalizing of customs declarations and other procedures, and the number of booths at the border.

The congestion function at rail BCPs is estimated so that the observed shipping volume
can be reproduced by the developed model; the congestion function at road BCPs is estimated
using the observed waiting time data from 2010, as recorded by CPMM (CAREC, 2011, 2012),
the observed traffic flow data at BCPs in 2010, which was collected by Tanaka et al. (2014),
and the Chinese customs data collected by ADB (2012).

3.4 Parameter Setting and Estimation of MICS-CA

The MICS-CA contains unknown coefficients within the congestion functions, which need to be estimated using empirical data. An O-D traffic flow matrix, transportation network structure, and level-of-service data in the transportation network must be prepared to estimate the MICS-CA.

3.4.1 Estimation of O-D traffic flow matrices

The O-D traffic flow matrix is estimated in four steps. The first step is setting the traffic analysis zones (TAZs). Five countries in CA (Kazakhstan, Kyrgyzstan, Turkmenistan, Tajikistan, and Uzbekistan) are divided according to the administrative units in each country. This follows the zoning system developed by Shibasaki et al. (2005). However, since no suitable statistical data other than Gross Regional Product (GRP) are available that are representative for the TAZs, this study estimated the TAZ-based traffic volumes assuming that the traffic volumes to and from the TAZs are proportional to their GRP, as recommended by Shibasaki et al. (2010a).

China is divided into 31 provinces following the zoning system proposed by Shibasaki et al. (2005), and Russia is divided into eight districts. Country-based TAZs are assumed for Armenia, Azerbaijan, Belarus, Georgia, India, Iran, Japan, Pakistan, Turkey, and Ukraine. Finally, the rest of the world is divided into continent-sized TAZs. The boundaries of these TAZs can represent the collective transportation links feeding into CA and its neighboring regions. In sum, 104 TAZs are used in this study.

The second step is integrating the O-D matrix of cargo flows transported via land with the corresponding one for maritime shipping, both of which are obtained from the actual tonnage-based bilateral trade data by transportation mode (IHS, 2013). This study covers trade by CA countries via land and maritime transportation as well as trade between the Eurasian countries by land transportation to highlight the transportation in CA. The O-D matrix in the second step uses the country-zoning system.

The third step is converting the tonnage-based O-D matrix into a vehicle/container-based O-D matrix. A ton-to-vehicle/container ratio of 0.1 is assumed for all international containers, implying that 10 tons of international cargo is loaded onto a trailer or truck in CA, on average. Although this assumption excessively simplifies the reality, poor availability of data for the number of vehicles passing through the BCPs did not enable us to incorporate a variety of ratios.

The final step is estimating the 104 TAZ-based O-D traffic flow matrix using the country-based O-D matrices, which are made in the second step. As the GRPs of the provinces in Turkmenistan are not available, the traffic volumes to and from the TAZs in Turkmenistan are assumed to be proportional to their population, also as recommended in Shibasaki et al. (2010a).

For the traffic flow from Country $R$ to Country $S$, let the volume be represented by $q_{RS}$. Country $R$ contains multiple TAZs $r (\in R)$, and Country $S$ also contains multiple TAZs $s (\in S)$. The traffic volume from $r$ to $s$ is estimated as:

$$q_{rs} = \frac{\sum_{r \in R} GRP_r \cdot \sum_{s \in S} GRP_s}{\sum_{r \in R} GRP_r} \cdot q_{RS}$$

(6)

where $GRP_r, GRP_s$ : GRPs in TAZs $r$ and $s$, respectively.

3.4.2 Establishment of transportation network
Figure 2 illustrates the worldwide network used in the MICS-CA. The land shipping network for the CA network (including road and rail networks) is based on the Asian Development Bank’s (ADB, 2009) network map and the worldwide GIS-based information provided by American Digital Cartography Inc. The existing land shipping networks for East and Southeast Asia created by Asia-Pacific Economic Cooperation (APEC, 2010) are also utilized. The ADC WorldMap™ is the information source for the networks in the rest of the Eurasian continent. The resulting land shipping network for the entire Eurasian continent covers 69,300 road links and 4,033 railway links, with total lengths of 2,909,252 km of road and 128,729 km of railway. The network also includes ferry links on the Caspian Sea.

Next, the maritime network is prepared, which covers the seaports used mainly for international trade to and from CA in addition to the ports (one per TAZ). For analytical simplicity, a single port is assumed to exist in China and four ports are assumed in Russia. Finally, the O-D points are selected from the network nodes. Within Eurasia, the O-D points are assumed to be the capital and provincial capital cities in the country-based and province-based zones, respectively. Outside of the Eurasian continent, a unique O-D point is set in any continent or region that is directly connected to the ports in the corresponding continent or region using hypothetical access links.

### 3.4.3 Link cost functions by link type

The generalized link cost for each link is generally estimated as the sum of the freight charge and the time cost, which is computed by multiplying the link travel time by the average value of time for the cargo owner. They are defined according to the type of link: road, ferry, rail, BCP, or transshipment. The rail and BCP links include link performance functions to reflect the fact that traffic flows are interrupted by the limited capacities of rail facilities and cross-border roads.

First, the generalized cost of a road link is assumed to be:

\[ G_{L,\text{road}} = C_{LF,\text{road}} + \omega \cdot T_{L,\text{road}} \]  

(7)
where

\[ G_{L, \text{road}} \] : generalized unit cost of the road link (US$/twenty-foot equivalent unit [TEU]),

\[ C_{LF, \text{road}} \] : unit freight of the road link (US$/TEU),

\[ T_{L, \text{road}} \] : travel time on the road link (hours),

\[ \omega \] : value of time (US$/TEU/hour),

\[ k_{\text{road}} \] : unit variable cost per kilometer of the road link (US$/TEU/km),

\[ l \] : length of the link (km), and

\[ v_{\text{road}} \] : average travel speed on the road link (km/hour).

The variable cost is doubled because most vehicles carry their goods only one way, transporting nothing on return trips.

Second, the generalized cost of a ferry link is assumed to be:

\[ G_{L, \text{ferry}} = C_{LF, \text{ferry}} + \omega \cdot T_{L, \text{ferry}} \] (10)

\[ C_{LF, \text{ferry}} = C_{\text{ferry}} + 2l_{\text{ferry}} \] (11)

\[ T_{L, \text{ferry}} = l_{\text{ferry}} / v_{\text{ferry}} \] (12)

Third, the generalized cost of a rail link is assumed to be:

\[ G_{L, \text{rail}} = C_{LF, \text{rail}} + \omega \cdot T_{L, \text{rail}} \] (13)

\[ C_{LF, \text{rail}} = 2l_{\text{rail}} \] (14)

\[ T_{L, \text{rail}} = l_{\text{rail}} / v_{\text{rail}} \] (15)

Fourth, the generalized costs of BCP links (road and rail) are assumed to be:

\[ G_{B, \text{road}} = C_{B, RS} + \omega \cdot T_{B, RS, \text{road}} \] (16)

\[ T_{B, RS, \text{road}} = T_{DX, R} + T_{DM, S} + (T_{CX, R} + T_{CM, S}) \left\{ 1 + \alpha_{4}x^{\alpha_{2}} \right\} \] (17)

\[ G_{B, \text{rail}} = C_{B, RS} + \omega \cdot T_{B, RS, \text{rail}} \] (18)

\[ T_{B, RS, \text{road}} = T_{DX, R} + T_{DM, S} + (T_{CX, R} + T_{CM, S}) \left\{ 1 + \beta_{1}(x + x_{\text{contra}})^{\beta_{2}} \right\} \] (19)
where

\[ G_{B, \text{road}} \]: generalized unit cost of the road BCP link (US$/TEU),
\[ C_{B, RS} \]: unit cost of crossing the BCP from Country \( R \) to Country \( S \) (US$/TEU), including the cost of document preparation and customs clearance in both the exporting country as well as the importing country,
\[ T_{B, RS, \text{road}} \]: time required to cross the road BCP from Country \( R \) to Country \( S \) (hours), including not only the waiting time at the borders and customs clearance but also the time for document preparation in the exporting and importing countries,
\[ T_{DX, R} \]: document preparation time required for exporting goods from Country \( R \) (hours),
\[ T_{DM, S} \]: document preparation time required for importing goods into Country \( S \),
\[ T_{CX, R} \]: time required for customs clearance and technical control when exporting goods from Country \( R \) (hours),
\[ T_{CM, S} \]: time required for customs clearance and technical control when importing goods into Country \( S \) (hours),
\[ x \]: traffic volume (TEU/year),
\[ x_{\text{contra}} \]: contraflow of the link (TEU/hour),
\[ G_{B, \text{rail}} \]: generalized unit cost of a rail BCP link (US$/TEU),
\[ T_{B, RS, \text{rail}} \]: time required to cross the rail BCP from Country \( R \) to Country \( S \) (hours), and
\[ \alpha_1, \alpha_2, \beta_1, \beta_2 \]: unknown parameters on the congestion terms.

These link functions assume that the time required for document preparation at borders is independent of the traffic volume, while the waiting time for customs clearance and technical control at borders depends only on the traffic volume. Although other factors related to BCP capacity (such as the number of windows, the efficiency of the process, the commodity transported, and the customs system) may also influence the border waiting time, these factors are not included in the estimation because of data unavailability. Additionally, the congestion function shown in Equation (19) also assumes that the time required for customs clearance and technical control at a road BCP depend on two traffic flows in both directions: traffic flow and contraflow, at a road BCP. Note that, in theory, four different congestion functions should be defined at one road BCP, that is: (1) a congestion function of the customs procedures for exporting at the BCP in Country \( R \), regarding a transport from Country \( R \) to Country \( S \); (2) that for importing at the BCP in Country \( S \), regarding a transport from Country \( R \) to Country \( S \); (3) that for exporting at the BCP in Country \( R \), regarding a transport from Country \( S \) to Country \( R \); and (4) that for importing at the BCP in Country \( S \), regarding a transport from Country \( S \) to Country \( R \). Equation (19) simplifies the above four cases into one function. Although we tried to formulate another congestion function that contains the traffic flow of one direction only, we do not use it because the estimation result of the congestion function is quite poor, mainly because of low data reliability of the time required for customs clearance and technical control under congested situations at road BCPs. The congestion function at rail BCPs shown in Equation (17) is estimated so that the observed shipping volume can be reproduced by the developed model because the quality of railway traffic data in particular is poorer than that of road traffic data (ADB, 2013c).
Finally, the generalized cost of a transshipment link for transportation mode \( m \) is assumed to be:

\[
G_{T,m,\text{on}} = C_{LF,\text{road}} + \omega \cdot (T_T + 0.5 I_m) \\
G_{T,m,\text{off}} = C_{LF,\text{road}} + \omega \cdot T_T
\]

where

\[
G_{T,m,\text{on}} : \text{generalized unit cost of the transshipment link for transportation from road to mode } m \text{ (US$/TEU), including the expected waiting time,} \\
G_{T,m,\text{off}} : \text{generalized unit cost of the transshipment link for transportation from mode } m \text{ to road (US$/TEU), including the expected waiting time,} \\
T_T : \text{time required to complete the transshipment (hours), and} \\
I_m : \text{service interval of transportation mode } m \text{ (hours).}
\]

The expected waiting time for transshipment should be decided by both service interval and the congestion of cargoes. However, the number multiplied by the service interval of transportation mode \( m \) is assumed to be 0.5 independently of traffic volumes in our research. This assumes that the average expected waiting time is equal to half of the railway/ferry service headway. Although we tried to formulate the other congestion function that the waiting time at transshipment link is increased by the traffic congestion on the connected railway links, we cannot use it because the results of our model with the congestion functions at the transshipment stations cannot reach convergence. There are mainly two potential reasons. One is that our transportation infrastructure network is too wide to incorporate cargo congestion at each transshipment station. Note that we developed the traffic analysis model focusing on transportation behavior at the border-crossing points rather than that at the domestic transshipment points because this study highlights the impact of infrastructure projects, not on the domestic traffic, but on trade and international traffic flows. The other possible reason is because of the poor data reliability of the waiting time for transshipment at each station.

### 3.4.4 Parameter setting

Table 1 summarizes the parameters used in the model. The parameters for the value of time, average speed, and unit variable cost for ferry links follow the data given by Shibasaki and Watanabe (2012). The unit variable costs per kilometer for roads and railways are assumed using the data from the CPMM annual report (CAREC, 2011). The time and cost for crossing BCPs are collected from the *Doing Business Report* (World Bank, 2013).

The two parameters in the BPR function for the rail link in Equation (17) (i.e. \( \alpha_1 \) and \( \alpha_2 \) ) are calibrated through traffic assignment using the UE principle, so that the observed traffic volumes at the seven BCPs (Tanaka et al., 2014) are approximately equal to the estimated traffic volumes at the BCPs (since the data on the volume of rail transport are not available). The calibration results yield \( \alpha_1 = 4.15 \times 10^{-5} \) and \( \alpha_2 = 1.002 \).

<table>
<thead>
<tr>
<th>Table 1. Parameters Used in Simulation Analysis</th>
<th>Road</th>
<th>Railway</th>
<th>Ferry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of time ( \text{US$/TEU/hour} )</td>
<td>3.39</td>
<td>3.39</td>
<td>3.39</td>
</tr>
<tr>
<td>Average speed ( \text{km/hour} )</td>
<td>39.4</td>
<td>30.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Service interval ( \text{Hour} )</td>
<td>24.0</td>
<td>168.0</td>
<td></td>
</tr>
<tr>
<td>Unit variable cost ( \text{US$/TEU/km} )</td>
<td>1.068</td>
<td>0.638</td>
<td>0.075</td>
</tr>
<tr>
<td>Transshipment time ( \text{Hour} )</td>
<td>24.0</td>
<td>4.0</td>
<td></td>
</tr>
</tbody>
</table>
3.4.5 Estimation of unknown parameters in link cost functions

The unknown parameters $\beta_1$ and $\beta_2$ in Equation (19) related to congestion when crossing BCPs are estimated via simple regression analysis on the observed data. The observed data for the traffic volume passing through borders and the ratio of the time required for customs clearance and technical controls in congested situations compared with those in uncongested situations are available for seven BCPs (Tanaka et al., 2014). As a result of the single regression, $\beta_1$ and $\beta_2$ are estimated to be 0.631 ($t = -3.09$) and 0.447 ($t = 4.22$), respectively. Figure 3 shows the estimated ratio versus the observed ratio of the time required for customs clearance and technical controls in congested situations compared with those in uncongested situations ($R^2 = 0.706$).

3.4.6 Results of traffic assignments

Current O-D cargo volumes are assigned to the transportation network using the above parameters to check the model’s reproducibility. The convergence criterion in UE assignment is

$$\sqrt{\sum_a (x'_a - x_{a-1}'^i)^2 / \sum_a x'_a} < 4 \times 10^{-7},$$

where $x'_a$ is the link flow of link $a$ in the $i^{th}$ iteration.

Figure 4 shows the traffic volume estimated via the MICS-CA versus the observed traffic volume at the six road BCPs used in the study by Tanaka (2014). Figure 4 shows that the estimated model adequately reproduces the magnitude of the relationship between the observed and the estimated traffic volumes. However, it underestimates the traffic volume at Irkeshtan, Alat-Farap, Sarasiya-Pakhtaabad, Torugart, and Tazhen-Dautota. This is mainly because the cost of crossing a railway BCP is underestimated in the model. Railway transportation involves several stakeholders that are not described in the model. Although rolling stock providers, the national railway company, and other control authorities are involved in railway transport, there are insufficient data and research to forecast their transportation behavior. Figure 5 shows the traffic volume estimated via the MICS-CA versus the observed traffic volume at the BCPs between China and Central Asian countries, which were shown in the study by ADB (2012). Figure 5 shows that the estimated model reproduces the modal choice between railway and road.
3.5 Computation Process with GTAP and MICS-CA

Iterative calculation between the GTAP and the MICS-CA describes the convergence between trade demand and trade cost as shown in Figure 1. The GTAP model enables us to estimate the impact of changes in trade cost on trade demand, while the impact of trade volume change on trade cost can be analyzed with the MICS-CA. The O-D matrices need to be converted to connect the two models.

Three conversion calculations were used to prepare the input of the MICS-CA in order to assume the impact of change in trade demand outputted from the GTAP. First, the O-D matrices in the GTAP use the GTAP-region-zoning system, while the O-D matrices in the MICS-CA use the TAZ system. The MICS-CA uses smaller zoning systems to evaluate the transportation network development. It is assumed that the traffic volumes to and from a TAZ are proportionate to the GRP of a TAZ as shown in Section 3.4.1. Second, the trades demand O-D
matrices in the GTAP use the value-based system, while the trades demand O-D matrices in the MICS-CA use the TEU-based system because freight forwarders are assumed to decide their route and mode mainly based on the cargoes’ volume. The necessary coefficients (such as share of land transportation, share of maritime transportation, ratio of value to weight in each transportation mode, containerization rate, and ratio of weight to TEU in maritime transportation) are estimated for each commodity and each O-D pair by using the World Trade Service as described in Section 3.4.1. Third, the commodities are aggregated into seven commodities in the GTAP analysis, while the type of goods is neglected in the MICS-CA analysis for analytical simplicity.

4. CASE ANALYSIS

The case analysis assumes three cases: (1) a baseline case in which the border-crossing services do not improve while the transportation costs remain unchanged; (2) a congestion case in which the border-crossing services do not improve but the transportation costs change; and (3) an improvement case in which the border-crossing services improve and the transportation costs also change. The improvement case assumes that the border-crossing time in CA is 35% lower in 2020 than in 2010. This aligns with the target milestone set by the CAREC, which estimates that the average border-crossing time along the CAREC corridors will be reduced to 5.7 hours (CAREC, 2011). The establishment of a customs union and the modernization of customs clearance procedures are also assumed to reduce the waiting time at BCPs, which is expected to contribute to achieving this target milestone. The equilibrium trade volumes and costs are estimated through iterative computations of the GTAP model and the MICS-CA.

First, the monetary-based O-D flow matrices in 2010, 2015, and 2020 are estimated via the GTAP model. This is the baseline case. For the estimation, changes in the following factors within each region are forecast in alignment with Shibasaki et al. (2010): population; skilled labor; unskilled labor; capital; natural resources; total factor productivity; and the customs union in Belarus, Russia, and Kazakhstan. Subsequently, the status of the international economy in 2010, 2015, and 2020 is estimated via three sequential simulations. The first simulation estimates changes from 2007 to 2010 by inputting changes in the factors listed above into the GTAP model, along with 2007 data. The second simulation estimates changes from 2010 to 2015 by inputting changes in the above factors into the GTAP model, along with the 2010 data estimated in the first simulation. The third simulation estimates changes from 2015 to 2020 by inputting changes in the above factors into the GTAP model, along with the 2015 data estimated via the second simulation. The detailed data inputted into the GTAP model in the case analysis is shown in a paper by Tanabe et al. (2014).

Next, the monetary-based O-D flow matrices in 2015 and 2020 (with congestion effects) are estimated through iterative computation using the GTAP model and the MICS-CA until both the trade cost outputted from MICS-CA and the trade demand outputted from GTAP converge. This case reflects the expectation that trade demand and trade cost are influenced by one another. This, for example, assumes that a growth of trade demand causes longer border-crossing times and increases trade costs, which decreases trade demand, and which influences trade costs until the changes in both trade costs and trade demand during a single iteration become sufficiently small. This represents the congestion case.

Finally, the monetary-based O-D flow matrices in 2015 and 2020 are estimated through iterative computation using the GTAP model and the MICS-CA, assuming that the border-crossing time in CA is reduced by 19.4% every 5 years from 2010 to 2020, which assumes that the border-crossing time becomes 35% lower in 2020 than that in 2010. This represents the
improvement case.

Figure 6 shows the changes in international traffic flows due to reduced waiting time at BCPs. Figure 7 shows the convergences for country-based trade volumes and trade costs in the iterative computation for the congestion case from 2015 to 2020. The convergence index for trade volume is defined as

\[ \sum_{RS}^{t} \frac{X_{RS}^t - X_{RS}^{t-1}}{\sum_{RS}^{t} X_{RS}^t} \],

where \( X_{RS}^t \) is the trade volume from Country \( R \) to Country \( S \) in the \( t \)th iteration; and the convergence index for trade cost is defined as

\[ \sum_{RS}^{t} \frac{C_{RS}^t - C_{RS}^{t-1}}{\sum_{RS}^{t} C_{RS}^t} \],

where \( C_{RS}^t \) is the trade volume from Country \( R \) to Country \( S \) in the \( t \)th iteration. We assume that the convergence criterion is \( 1.0 \times 10^{-5} \). The trade cost is estimated using a weighted-average transportation cost between the TAZs, using the share of TAZ-based traffic volumes as the weighting parameters. Figure 7 shows that the fifth iterative computation satisfies the convergence criterion. The results of the fifth iteration are used in the following discussions.

Figure 8 shows the simulated trade volumes in 2010, 2015, and 2020 in the three cases. First, the total trade volume to and from CA in the congestion case is 1.2% lower than that in the baseline case. The trade volumes from the rest of the erstwhile Soviet Union (RSU; defined in the GTAP model as Tajikistan, Turkmenistan, and Uzbekistan) to Russia, from Kyrgyzstan
to Russia, and from the RSU to Kazakhstan in the congestion case are lower than those in the baseline case by 14%, 4%, and 6%, respectively, whereas the trade volumes from Kyrgyzstan to China and from the RSU to China in the congestion case are higher than those in the baseline case by 1% and 5%, respectively. This means that the destination of trade from Kyrgyzstan or the RSU has been shifted from Russia to China because of traffic congestion. This is because exporting to Russia requires multiple border crossings, and the traffic congestion at the BCPs increases the travel time.

Second, the trade volumes in the improvement case are higher than those in the baseline case from the CA countries and from Russia. This indicates that infrastructure improvement contributes to enhanced regional trade. However, the trade volumes from Kyrgyzstan to Kazakhstan, from the RSU to Kyrgyzstan, from the RSU to Kazakhstan, from Russia to Kyrgyzstan, and from Russia to the RSU increase from 2010 to 2015 but decrease from 2015 to 2020. This is because traffic congestion becomes so serious for those O-D pairs that the travel time increases significantly from 2015 to 2020.

Figure 8. Simulation Results of Country-based O-D Trade Volumes from 2007 to 2020 (Trade Volume is 100 in 2007)
Figure 9 shows the simulated unit trade costs per TEU in 2010, 2015, and 2020 in the three cases. First, the trade costs in the baseline and congestion cases increase from 2010 to 2020; in particular, those from Kyrgyzstan to Russia, from the RSU to Russia, and from Russia to Kazakhstan increase by 25%, 9%, and 5%, respectively. They cause a decrease in traffic volumes from Kyrgyzstan/RSU to Russia and an increase in traffic volume from Kyrgyzstan/RSU to China, as shown in Figure 8.

Second, the trade costs in the improvement case decrease from 2010 to 2015 and then increase from 2015 to 2020 in many O-D pairs. This U-shaped change in trade costs implies that infrastructure investments contribute to a reduction in the short-term trade costs; however, in the long run, this is overwhelmed by increased traffic congestion (due to the sharp increase in trade volumes). This suggests that further improvements in transportation services are required to overcome the expected growth in CA trade.
5. CONCLUSIONS

This paper developed a computable model to estimate the impacts of improvements in border-crossing services on traffic flow patterns in CA. Using the GTAP model and the MICS-CA, three cases were simulated. The results showed that border-crossing service improvement significantly decreases international transportation costs and increases trade volumes to and from CA in the short run; however, regional trade growth causes traffic congestion, leading to an increase in international transportation costs. This increase in costs could reduce trade volume to and from CA in the long run.

There are numerous issues that should be addressed in future research. First, the cost functions used in this study did not fully address all the transportation issues in the CA region. For instance, differences in the rail track gauge and in the capacities and services at logistics hubs would affect the transshipment time at intermodal points; however, these factors were not explicitly considered in our model. Although our approach was able to approximate such traffic congestion in transshipments, a more detailed formulation would improve the reliability of the MICS-CA. Second, our model assumed that the average border-crossing time is dependent only on the traffic flows; however, it is influenced by other factors as well. For example, CAREC (2012) reports that the newly introduced customs union makes the customs clearance process complex and causes delays in border processes. These factors should be examined to enable a better estimation of the process times required at the borders when there is congestion. Third, our analysis used the data agglomerated by Tanaka et al. (2014) and by ADB (2012) in order to overcome poor data availability. More international cargo flow data for CA would help to further validate the model. Additionally, a stochastic approach such as the stochastic user equilibrium (SUE) could be applied to route choice or modal choice in the MICS-CA if more data on international cargo flows were available. Finally, the study applied the developed model to a limited number of cases only; other cases that reflect CAREC-related policies could be investigated in future research.

REFERENCES

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