

JUNE 2017

Safety on the New Silk Road

Assessing Kazakhstan's Highways

EDITOR

Jonathan E. Hillman

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CSIS

CENTER FOR STRATEGIC &
INTERNATIONAL STUDIES

A REPORT OF THE
CSIS RECONNECTING ASIA PROJECT

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The second experiment was testing a new model for scholarly collaboration. We convened an international team of specialists, who worked across time zones and juggled their own scholarly and professional pursuits. This report is the product of their diverse perspectives and collective expertise. We are grateful for the energy and enthusiasm they brought to this endeavor, which could serve as a model for investigating other aspects of Asia's infrastructure competition and for CSIS's research more broadly.

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Executive Summary

For developing economies like Kazakhstan, Asia's infrastructure push offers opportunities to improve road safety. In Kazakhstan, road crashes are estimated to cost \$9 billion annually, or nearly 4 percent of gross domestic product (GDP). Kazakhstan is also a keystone for regional infrastructure investment programs such as the United Nations' Asian Highway Network (AHN), the Asian Development Bank's Central Asia Regional Economic Cooperation (CAREC) program, and more recently, China's "Belt and Road" initiative. To help set priorities within these overlapping initiatives, this study analyzes road quality and crash data covering approximately 13,000 kilometers of highways, or 13.4 percent of Kazakhstan's highway network. Within this sample, most roads are undivided with two lanes and rated below "good" condition. Most crashes are related to infrastructure deficiencies and noncompliance of the drivers to traffic rules and regulations. A series of maps identifies priority areas for improvement. Building on this analysis and a review of international best practices, cost-effective infrastructure measures are recommended for improving connectivity and road safety.

01

Introduction

Road safety is a local challenge with global public health and development implications. Every year, road crashes kill 1.25 million people and injure more than 50 million people around the world, exceeding deaths from malaria and HIV-related illnesses.¹ As the leading killer of young people between the ages of 15 and 29 years, road crashes push households into poverty and strain national healthcare systems.² Road traffic deaths and injuries cost many developing countries from 2 to 5 percent of GDP each year.³ In these and other ways, the human and economic toll is staggering.

Road safety is worse in low- and middle-income countries (LMIC), where rates can be more than double those in high-income countries (HIC).⁴ While plateauing globally since 2007,⁵ road fatalities in LMIC are expected to increase to almost 2 million per year by 2020.⁶ In Central Asia, road accidents are the 6th leading cause of death. This is higher than the global ranking (8th) and the ranking in Western Europe (24th), where serious efforts have been made to improve road safety. Most traffic crashes are preventable, and there is considerable evidence that interventions can improve road safety.⁷ Developed countries that have been successfully implementing these interventions have experienced corresponding reductions in road traffic deaths since the 1960s.⁸

Long overlooked, road safety has recently gained more attention internationally and within Central Asia. In September 2015, road safety was added to the UN Sustainable Development Goals.⁹ This agenda targets a 50 percent reduction in the absolute number of road traffic deaths and injuries by 2020 and aims to provide access to safe, affordable, and sustainable transport systems for all road users by 2030. In October 2016, CAREC ministers endorsed a road safety strategy that aims to cut in half the number of fatalities by 2030. This implies saving 23,000 lives

¹ World Health Organization, *Global Status Report on Road Safety 2015* (Geneva, 2015), http://www.who.int/violence_injury_prevention/road_safety_status/2015/en/.

² Nak Moon Sung and Mauricio Ríos, "Road Crashes Have More Impact on Poverty Than You Probably Thought," The World Bank Group Transport for Development Blog, February 25, 2015, <http://blogs.worldbank.org/transport/road-crashes-have-more-impact-poverty-you-probably-thought>.

³ Ibid.

⁴ Fred Wegman, "The Future of Road Safety: A Worldwide Perspective," *IATSS [International Association of Traffic and Safety Sciences] Research* 40, no. 2 (January 2017), <https://doi.org/10.1016/j.iatssr.2016.05.003>.

⁵ World Health Organization, *Global Status Report on Road Safety 2015*.

⁶ Wegman, "The Future of Road Safety."

⁷ Heidi Worley, "Road Traffic Accidents Increase Dramatically Worldwide," *Population Reference Bureau*, March 2006, <http://www.prb.org/Publications/Articles/2006/RoadTrafficAccidentsIncreaseDramaticallyWorldwide.aspx>.

⁸ Ibid.

⁹ World Health Organization, "UN General Assembly Adopts a Resolution on Improving Global Road Safety," April 15, 2016, http://www.who.int/violence_injury_prevention/media/news/2016/15_04/en/.

and 250,000 serious injuries every year, amounting to approximately \$16 billion per year.¹⁰ Meeting these ambitious goals will require resources and support from government officials.

For developing economies like Kazakhstan, Asia's infrastructure push offers opportunities to improve road safety. Among the 52 European and Central Asian countries examined in the World Health Organization's most recent report on road safety, Kazakhstan has the highest road traffic death rate.¹¹ Illustrating accidents by road segment, Figure 1 underscores the scale and severity of this challenge. Poor road infrastructure is a major exacerbating factor. An estimated 17 percent of Kazakhstan's highways fall below internationally recognized minimum standards, and only 3 percent of its highways meet the highest standard.¹² In Kazakhstan, road crashes are estimated to cost \$9 billion annually, or nearly 4 percent of GDP.¹³ The number of vehicles registered in Kazakhstan has more than doubled over the last decade,¹⁴ and as incomes and motorization rates continue rising, so will the importance of road safety. To address these challenges, the government of Kazakhstan is developing a wide-ranging national road safety strategy.¹⁵

Executing that strategy will require setting investment priorities. Every economy has finite resources to maintain, upgrade, and build roads. To be sure, road safety is not the only concern for infrastructure planning, which must balance a range of economic and social goals. In Kazakhstan, where roughly 45 percent of the population lives in rural areas, increasing roadway access is not only important for the safe transport of goods but also for creating access to emergency services, schools, and employment centers.¹⁶ Nor is infrastructure planning the only factor impacting road safety, which also depends on improving driver behavior and raising public awareness. Yet there is a strong link between bringing highways up to international standards and improving road safety.¹⁷

Improved roads can also contribute to greater regional connectivity, particularly in Central Asia, where large gaps remain. Kazakhstan is a keystone for regional infrastructure investment programs such as the United Nations' Asian Highway Network (AHN), the Asian Development Bank's Central Asia Regional Economic Cooperation (CAREC) program, and more recently, China's "Belt and Road" initiative. Domestically, an estimated \$9 billion in infrastructure investment is planned under the Nurly Zhol program, which was announced by Kazakhstan's President Nursultan Nazarbayev in November 2014.¹⁸ How can these programs, and the

¹⁰ Asian Development Bank, *Safely Connected: A Regional Road Safety Strategy for CAREC Countries, 2017–2030*, (February 2017), <http://dx.doi.org/10.22617/RPT178658-2>.

¹¹ Ibid.

¹² Rafis Abazov, "Kazakhstan Welcomes China's Belt and Road Initiative," *HKTDC Research*, April 20, 2016, <http://hkmb.hktdc.com/en/1X0A5WB1/hktdc-research/Kazakhstan-Welcomes-China%E2%80%99s-Belt-and-Road-Initiative>.

¹³ Asian Development Bank, *Safely Connected*.

¹⁴ Government of Kazakhstan, "Automobile Transportation," <http://stat.gov.kz/getImag?id=ESTAT099960>.

¹⁵ Yerbolat Uatkhanov, "Kazakhstan Develops Road Safety Plan, Fatalities Decline," *The Astana Times*, May 7, 2017, <http://astanatimes.com/2017/05/kazakhstan-develops-road-safety-plan-fatalities-decline/>.

¹⁶ Committee on Statistics of the Ministry of National Economy of the Republic of Kazakhstan, *Women and Men in Kazakhstan 2009–2013* (Astana, 2014), stat.gov.kz/getImag?id=ESTAT086608.

¹⁷ World Health Organization, *Global Status Report on Road Safety 2015*.

¹⁸ Republic of Kazakhstan, "Nurly Zhol: the \$9 Billion Path to the Future," *Invest in Kazakhstan 2015*, http://kazakhstan.newsdeskmedia.com/Images/Upload/Kazakhstan_2015/PDFs/Nurly_Zhol.pdf.

associated infrastructure investments, be prioritized and leveraged to ensure they advance both the national connectivity and safety agendas?

Figure 1. Traffic Accidents in Kazakhstan



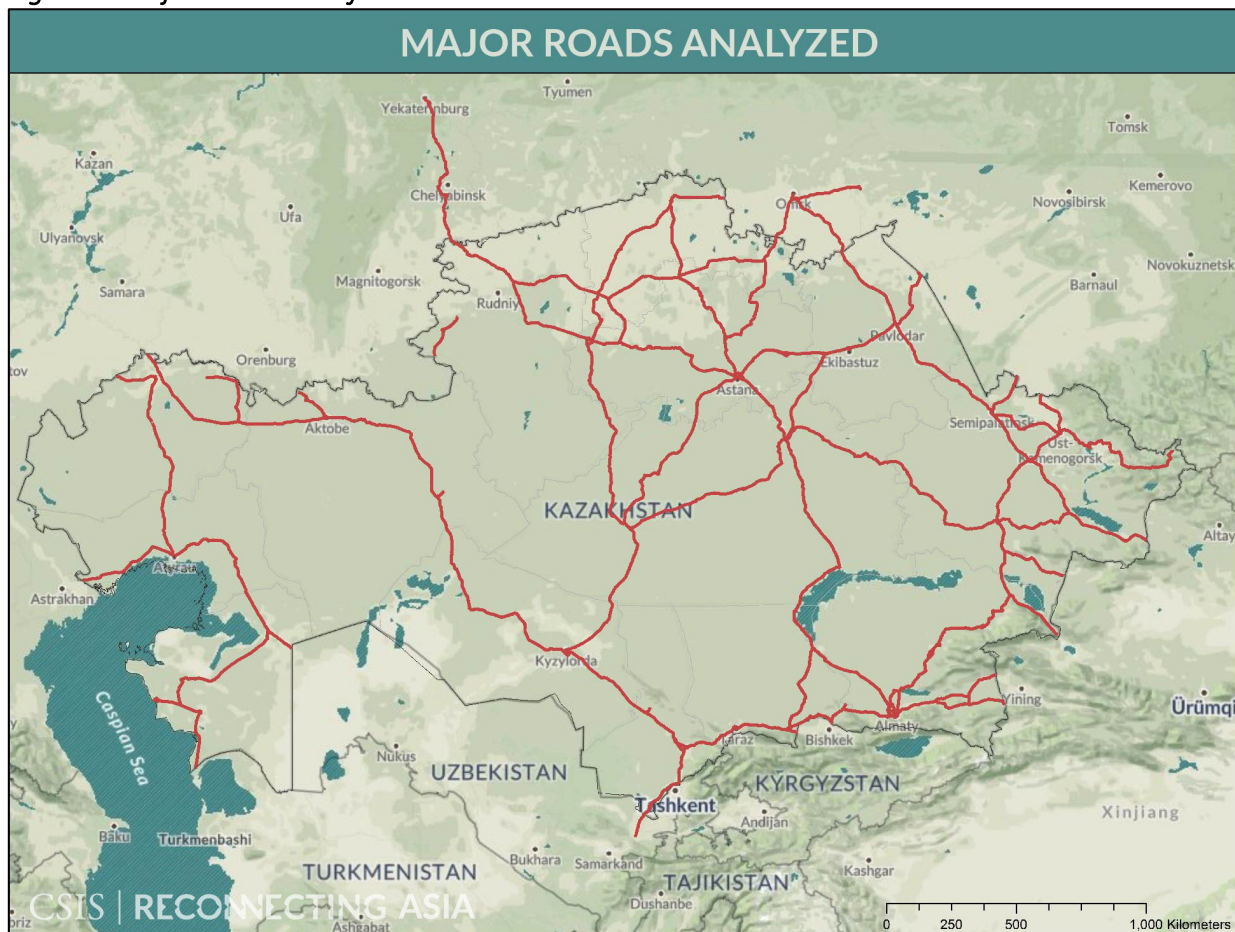
This report tackles that question in three parts. It begins by assessing road quality and crash data for selected AHN and CAREC roads. Using these findings, cost-effective safety measures are recommended to strengthen Kazakhstan's road network. These recommendations are based on a review of international best practices. Finally, a conclusion notes the limitations of this study and suggests areas for further research.

02

Analysis

This section analyzes approximately 13,000 kilometers of roads (illustrated in Figure 2), equivalent to 13.4 percent of Kazakhstan's highway network.¹⁹ It compares road quality to international standards and examines crash data. The quality analysis suggests that most roads are undivided with two lanes and rated below "good" condition. The crash analysis suggests that most crashes are related to infrastructure deficiencies and noncompliance of the drivers to traffic rules and regulations. A series of maps identifies priority areas for improvement.

Figure 2. Major Roads Analyzed



¹⁹ Republic of Kazakhstan Statistics Committee 2016, "Statistics Committee Official Internet Resource," http://www.stat.gov.kz/faces/wcnav_externalId/homeNumbersTransport;jsessionid=e-1E0f0SrTLxCqy3wCI4IPZYcvDpydkS3WNPe9KhyCxcGIAI3j_H!481998659!-1837500658?_adf.ctrl-state=qk2b29ewk_43\&_afLoop=584959611053105#%40%3F_afLoop%3D584959611053105%26_adf.ctrl-state%3Dh463pvdw_4.

The roads examined are part of two overlapping connectivity efforts. Supported by the United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP), the AHN aims to improve the highway systems in Asia by maximizing use of the continent's existing highways.²⁰ The CAREC program aims to accelerate economic growth and poverty reduction by facilitating the movement of goods and people through sustainable, safe, and user-friendly transport and trade networks.²¹

Quality Assessment

This section compares road conditions to international best standards and practices for safe road design and management. Of the roads examined, 76 percent are undivided two-lane roads, and more than 50 percent have not been upgraded to asphalt concrete. As Figure 3 shows, 45 percent of the AHN road segments have less than half of their surface in good condition. Studies have found that poor pavement conditions increase safety risks,²² with rougher pavement affecting light passenger vehicles even more than heavy freight vehicles.²³ Poor surfaces lead to higher speed variation between vehicles, making collisions more likely. Unpaved and poorly maintained roads also increase vehicle maintenance costs. In sum, roadway surfaces can impact both safety and efficiency.²⁴

These challenges are evident along the AHN. Design standards for the AHN were set in 1995 to standardize guidelines and minimum requirements across member countries.²⁵ Significant work remains to meet these requirements. Poor signage and potholes increase driving risks, particularly at night and in rural areas.²⁶ Although most roadway segments are categorized as having "good" or "fair" road surface conditions, the lack of sidewalks in urban areas and settlements and inadequate shoulders create dangerous conditions for road users. Of course, classification alone is no guarantee of safety. A Class I roadway segment provides the highest pavement standards for safety, yet roads containing Class I segments resulted in 325 accidents and 109 fatalities in 2010, roughly 58 percent of total accidents and 51 percent of total fatalities.

²⁰ United Nations Economic and Social Commission for Asia and the Pacific, "Asian Highway," <http://www.unescap.org/our-work/transport/asian-highway/about>.

²¹ Asian Development Bank, *CAREC Transport and Trade Facilitation Strategy 2020* (Astana, 2014), <https://www.adb.org/sites/default/files/institutional-document/34107/files/carec-ttfs-2020.pdf>; Central Asia Regional Economic Cooperation, "Regional Cooperation at Work in Central Asia," <http://www.carecprogram.org/index.php?page=carec-program>.

²² Peter Christensen and Arild Ragnow, *The Condition of the Road Surface and Safety: The Importance of Rut Depth, Roughness (IRI) and Changes in Cross-Slope for Road Safety* (Oslo: Institute of Transport Economics, 2006).

²³ Bernie-Anne King, "The Effect of Road Roughness on Traffic Speed and Road Safety" (BA diss., University of Southern Queensland, 2014).

²⁴ American Association of State Highway Transportation Officials (AASHTO), *A Policy on Geometric Design of Highways and Streets* (Washington, DC: 2011).

²⁵ United Nations Economic and Social Commission for Asia and the Pacific, *Asian Highway Classification and Design Standards* (Washington, DC: 2015), <http://www.unescap.org/resources/classification-and-design-standards>.

²⁶ Transport Corridor Europe-Caucasus-Asia (TRACECA), *Logistics Processes and Motorways of the Sea II—LOGMOS Master Plan—Annex 9.1. Kazakhstan Country Profile* (2013). http://www.traceca-org.org/fileadmin/fm-dam/TAREP/65ta/Master_Plan/MPA9.1KZ.pdf.

Figure 3. Asian Highway Network Surface Conditions



Three characteristics of the CAREC roads were evaluated: cross-sectional, horizontal, and vertical geometry. Importantly, these roads lack paved shoulders, which are useful for improving traffic safety.²⁷ The roads are essentially straight, which is preferable to roadways with sharp curves. However, it should be noted that very long tangents may make drivers drowsy, which increases the risk of a crash.²⁸ Three of the six routes²⁹ contain some steep grades (greater than 5 percent) and should be examined further with attention to combinations of horizontal curve and vertical grade.³⁰ Four out of six CAREC routes will be upgraded from two-lane undivided highways to four-lane divided carriageways, which are expected to decrease road crashes due to overtaking and head-on collisions.

²⁷ AASHTO, *A Policy on Geometric Design of Highways and Streets*; Rune Elvik et al., *The Handbook of Road Safety Measures* (United Kingdom: Emerald Group Publishing, 2004); Frank Gross and Paul P. Jovanis, "Estimation of the Safety Effectiveness of Lane and Shoulder Width: Case-Control Approach," *Journal of Transportation Engineering* 133, no. 6 (2007), [http://dx.doi.org/10.1061/\(ASCE\)0733-947X\(2007\)133:6\(362\)#sthash.XRIWFKoO.dpuf](http://dx.doi.org/10.1061/(ASCE)0733-947X(2007)133:6(362)#sthash.XRIWFKoO.dpuf); PIARC, *Roadway Safety Manual* (Paris: World Road Association, 2003).

²⁸ China Communications First Highway Survey Design and Research Institute, *Design Specification for Highway Alignment* (Beijing: Ministry of Transport of the People's Republic of China, 2006), <http://www.lancarver.com/upfiles/pdf/2014-04-04/040416355562.pdf>.

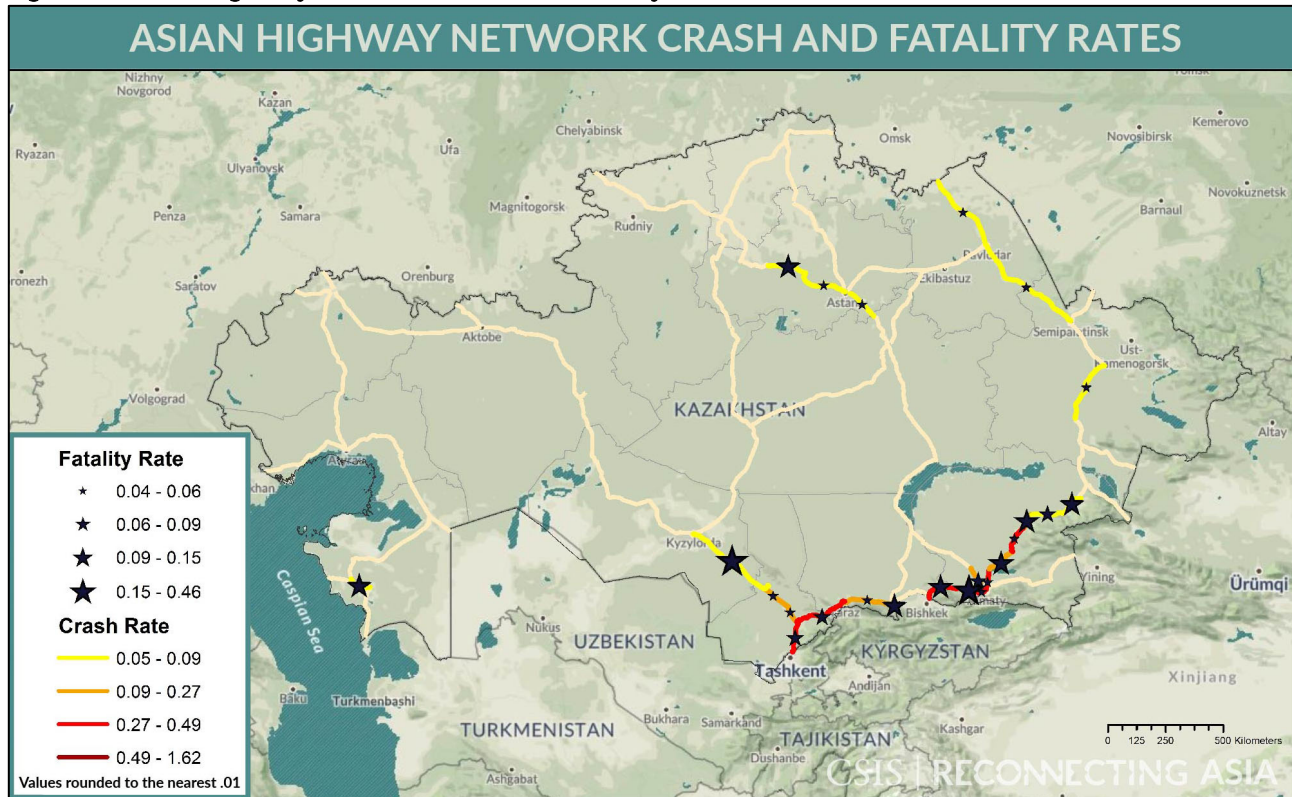
²⁹ The three routes are Karaganda-Burylbaital-Kurty, Taldykorgan-Kalbatay, and Atyrau-Astrakhan.

³⁰ Karin Bauer and Douglas Harwood, "Safety Effects of Horizontal Curve and Grade Combinations on Rural Two-Lane Highways," *Transportation Research Record: Journal of the Transportation Research Board* 2398 (2013), <http://dx.doi.org/10.3141/2398-05>.

Crash Assessment

Different crash analyses were conducted on AHN and CAREC roads, depending on the availability of data. For AHN roads, a crash rate per kilometer of roadway was calculated. This method provides a comparison per kilometer, so that it becomes easier to initially identify high crash locations before resorting to other methods, particularly for rural roadways (see Appendix B for more details).³¹ Using this method, Figure 4 indicates segments with a crash-per-kilometer rate greater than 0.05. The colors of the roads indicate crash frequency; lighter shades represent fewer crashes, and darker shades represent a greater number of crashes. Stars indicate the number of fatalities sustained from traffic accidents, with larger stars corresponding to higher numbers of fatalities. Areas with darker lines and larger stars indicate high-risk areas in greater need of effective countermeasures. As Figure 4 shows, crashes are concentrated in an arc along Kazakhstan's eastern periphery. If east-west overland trade expands in the coming years, as promoters of regional connectivity initiatives expect,³² these areas could experience additional traffic.

Figure 4. Asian Highway Network Crash and Fatality Rates



³¹ U.S. Department of Transportation Federal Highway Administration, *Roadway Safety Information Analysis: A Manual for Local Rural Road Owners* (Washington, DC: 2010), https://safety.fhwa.dot.gov/local_rural/training/fhwasaxx1210/s3.cfm.

³² Wade Shepard, "The Western Europe-Western China Expressway to Connect the Yellow Sea with the Baltic," *Forbes*, July 10, 2016, <https://www.forbes.com/sites/wadeshepard/2016/07/10/the-western-europe-western-china-expressway-to-connect-the-yellow-sea-with-the-baltic/#59cd12b36c95>.

Four analyses were conducted for the CAREC corridors. Figure 5 plots crash severity and shows that Karaganda-Burylbaital-Kurty is the road segment with the most fatalities for all types of crashes. Figure 6 shows the main types of crashes reported per road segment. Figure 7 shows the causes of the crashes per road segment, suggesting that overtaking error and speed were the leading causes. Crash investigations tend to overestimate driver error and underestimate other factors, including poor road design, so these results should be viewed cautiously. Finally, critical crash rates per road segment were calculated (see Appendix B for further details). Figure 8 illustrates the critical crash rate for each of the six CAREC corridors, with darker road segments indicating a higher rate.

Figure 5. Crash Severity of Six Roads in CAREC Corridor

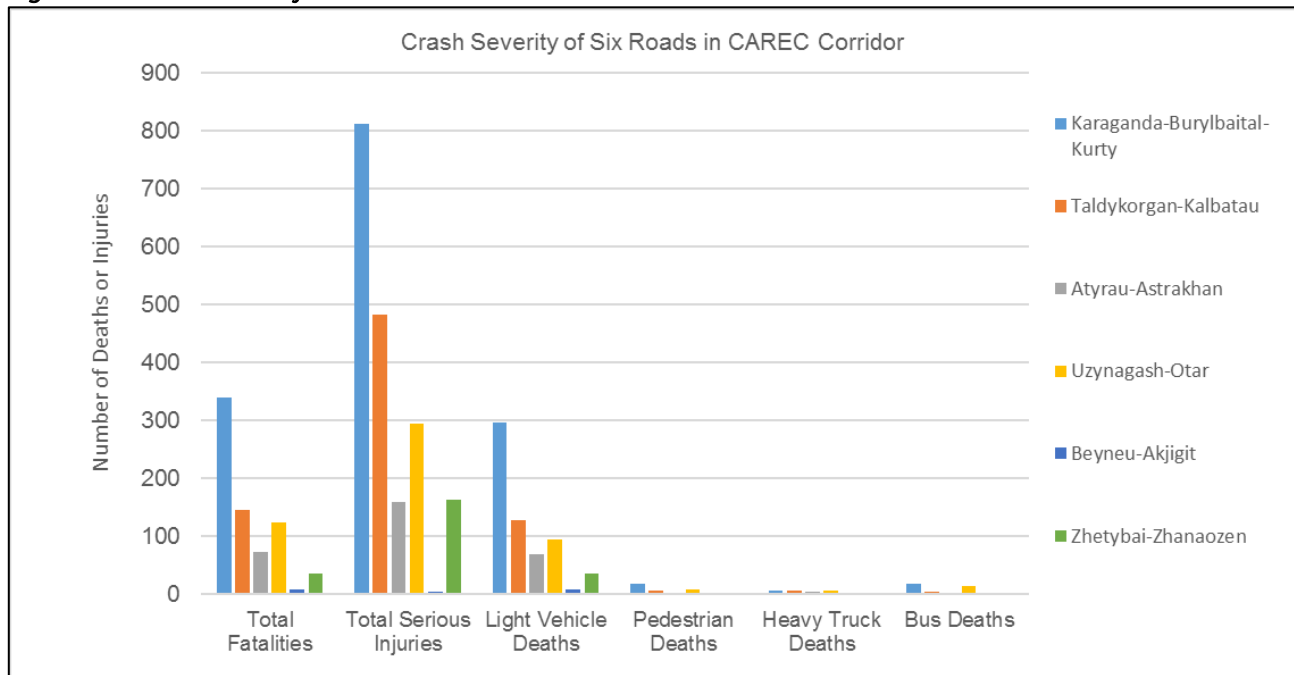


Figure 6. Collision Type per CAREC Road Segment

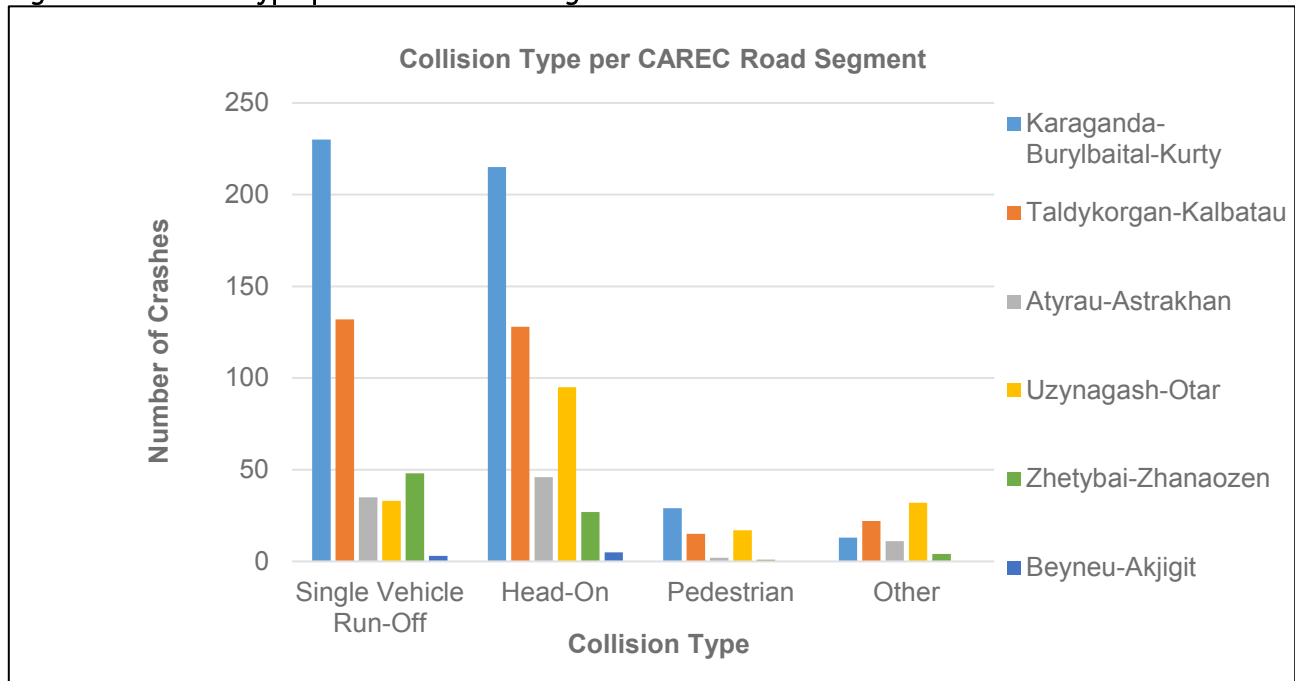


Figure 7. Reasons for Crashes per CAREC Road Segment

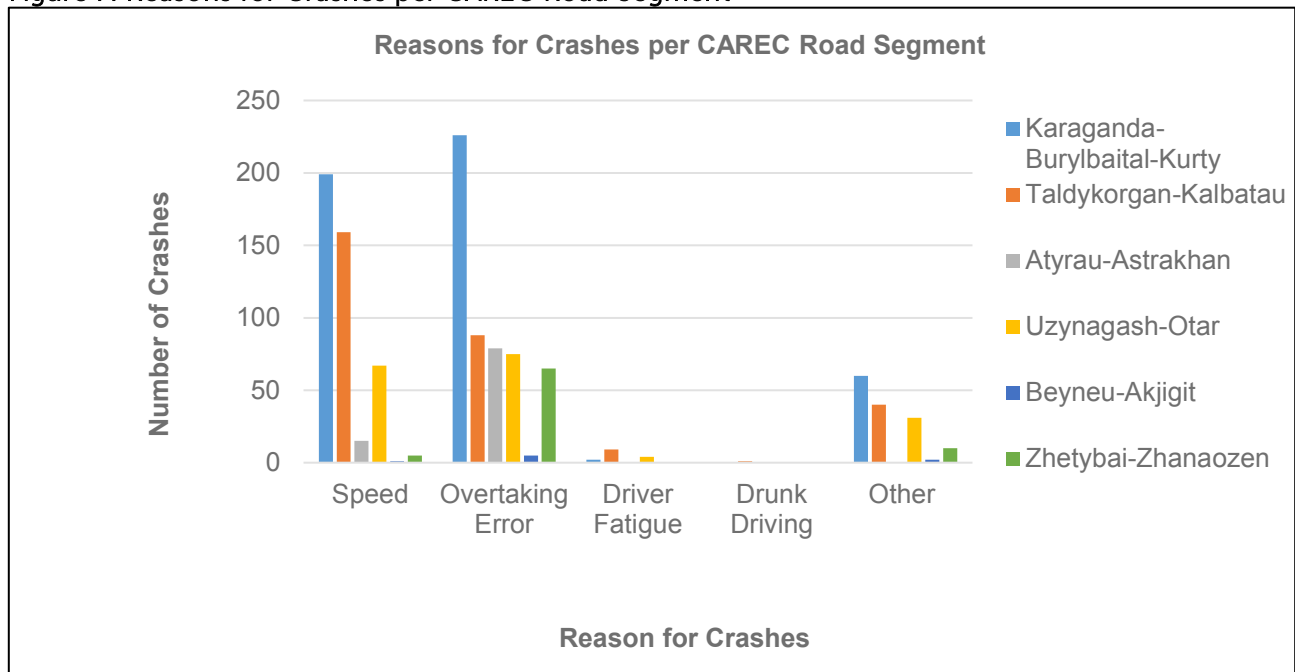
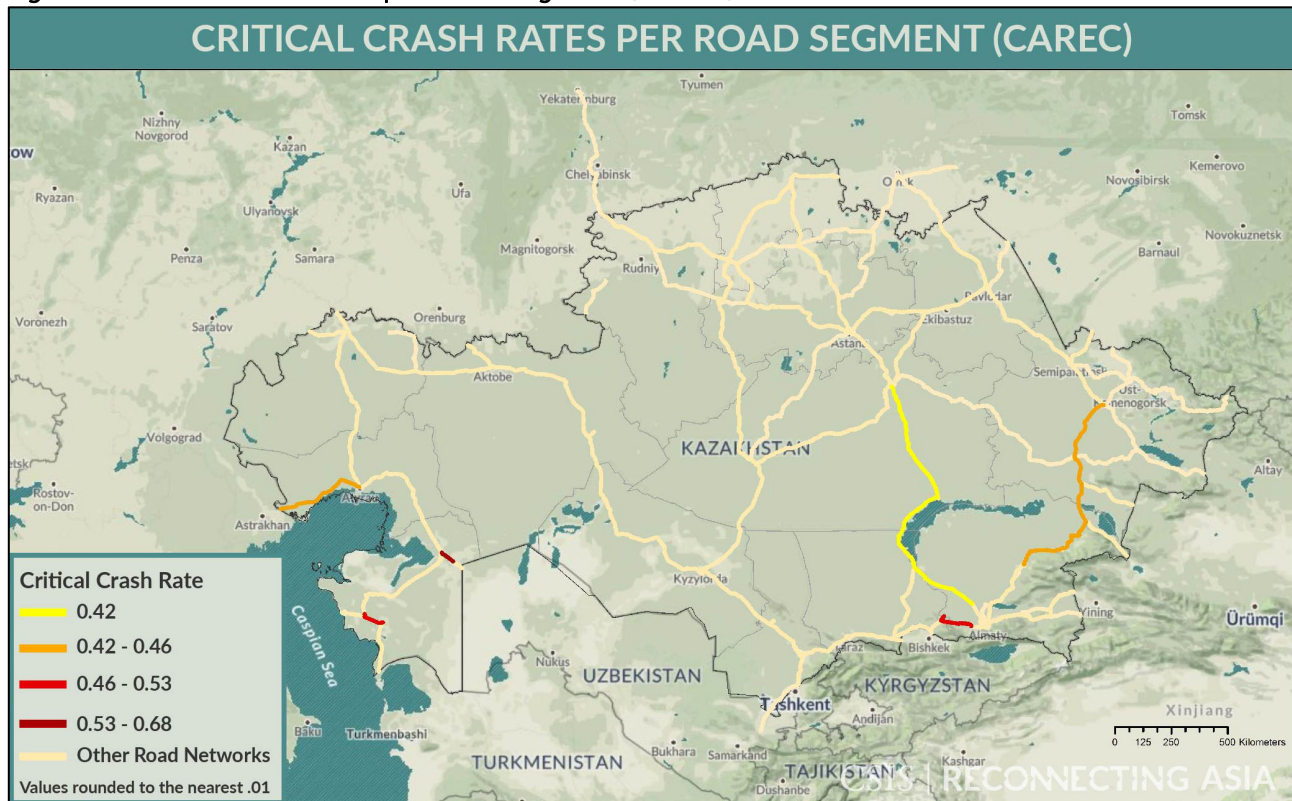


Figure 8. Critical Crash Rates per Road Segment (CAREC)



Limitations

This analysis has several limitations. First, although it draws from the latest publicly available sources, the underlying quality and crash data would benefit from being updated. For example, it is possible that roads have been improved since the data was collected. Furthermore, better crash reporting could influence the results. It is not unusual for crashes to be underreported in rural areas. Second, additional data sources could facilitate a deeper analysis. Particularly useful would be information about road usage. By adjusting for how heavily roads are used, it would be possible to identify areas where crashes are statistically more likely despite better road conditions. These results can be updated as additional data becomes available.

Recommendations

This section recommends infrastructure measures to improve Kazakhstan's road safety and regional connectivity. To be sure, infrastructure improvements are necessary but not sufficient. Enforcing traffic laws,³³ increasing public awareness,³⁴ and educating drivers³⁵ are also critical safety measures, but they are beyond the scope of this study. In this section, cost-effective road safety solutions are recommended based on the preceding analysis and a literature review of international best practices.

Combining quality and crash analysis, Table 1 provides a menu of countermeasures to minimize road crashes, fatalities, and critical injuries. On-the-ground inspections will help road authorities decide which of these countermeasures are most appropriate for a given road segment. The CAREC data allows for a more localized set of recommendations. Table 2 summarizes these recommendations and associates them with individual road segments.

This study also underscores the importance of road safety audits, data collection, and information sharing. Road safety audits can be conducted at any stage of a roadway life-cycle to provide greater insight. They require time and resources, but studies have found the benefits far exceed costs.³⁶ Data collected from road safety audits could be shared with international institutions and the public more broadly. In recent years, Kazakhstan has been making more information available through its Ministry of National Economy³⁷ and road authorities.³⁸ Providing regular updates with greater detail on road quality and crashes would help inform policy decisions and related research. It would also demonstrate Kazakhstan's progress in this important area.

³³ Dominic Zaal, *Traffic Law Enforcement: A Review of the Literature* (Monash University Accident Research Center, 1994), 2, http://www.monash.edu/___data/assets/pdf_file/0019/216343/muarc053.pdf.

³⁴ Judy J. Fleiter, Ioni M. Lewis, and Barry C. Watson, "Promoting a More Positive Traffic Safety Culture in Australia: Lessons Learnt and Future Directions" (paper presented at the Australasian College of Road Safety Conference, Adelaide, Australia, November 6–8, 2013), 1, <http://eprints.qut.edu.au/64494/2/64494.pdf>.

³⁵ Ashish Verma et al., "Recommendations for Driver Licensing and Traffic Law Enforcement in India Aiming to Improve Road Safety," *Current Science* 100, no. 9 (May 10, 2011): 1375, <http://www.currentscience.ac.in/Volumes/100/09/1373.pdf>.

³⁶ PIARC, *Roadway Safety Manual*.

³⁷ Ministry of National Economy of the Republic of Kazakhstan, "Official Statistics Operational Data," http://www.stat.gov.kz/faces/wcnav_externalId/homeNumbersTransport?_adf.ctrl-state=qk2b29ewk_43&_afLoop=595406511412525#%40%3F_afLoop%3D595406511412525%26_adf.ctrl-state%3D14nel4fmy_4.

³⁸ Kazavtozhol, <http://kazavtozhol.kz/index.php/ru/>.

Table 1. Summary of Countermeasures

Primary Contributor to Road Crash	Infrastructure Improvement
Run-Off Crashes on Curves	Sign and Pavement Marking Improvements Central Hatching Post-Mounted Delineators and Chevrons Edge Lines Shoulder and Edge Line Rumble Strips Pavement Markings Over Rumble Strips Adequate Driver Rest Areas Motorcycle Attenuating Devices "Forgiving" Poles Advanced Warning Signs Traffic Calming Measures High-Friction Surface Technologies
Run-Off Crashes on Straight Portions	Sign and Pavement Marking Improvements Shoulder and Edge Line Rumble Strips Pavement Markings Over Rumble Strips Roadside Cable Barriers Wider Longitudinal Pavement Markings Safety Edges Adequate Driver Rest Areas "Forgiving" Poles
Head-On Crashes	Raised Pavement Markers Median Barriers Central Hatching Centerline Rumble Strips
Crashes at Junctions/Intersections	On-Pavement Horizontal Signing Longitudinal Channelizers Traffic-Calming Measures Advanced Warning Signs High-Friction Surface Technologies Automated Enforcement
Pedestrians Crashes	On-Pavement Horizontal Signing Traffic-Calming Measures Sidewalks in Urban Areas
Speed	Traffic-Calming Measures Speed Displays Automated Enforcement
Overtaking	Traffic-Calming Measures Automated Enforcement
Fatigue	Sign and Pavement Marking Improvements Shoulder and Edge Line Rumble Strips Pavement Markings Over Rumble Strips Adequate Driver Rest Areas
U-turns	On-Pavement Horizontal Signing U-turn Lanes Traffic-Calming Measures Clear Advanced Signage

Table 2. Countermeasures for CAREC Roads

Countermeasures for CAREC Roads			
Road Segments	Primary Crash Type	Primary Cause	Low-Cost Countermeasures
Atyrau-Astrakhan	Head-on Crash	Overtaking Error	Raised Pavement Markers Median Barriers Central Hatching Centerline Rumble Strips Traffic-Calming Measures Automated Enforcement
Uzynagash-Otar			
Beyneu-Akjigit			
Karaganda-Burylbaital-Kurty	Single Vehicle Run-off	Overtaking Error	Sign and Pavement Marking Improvements Central Hatching Post-Mounted Delineators and Chevrons Edge Lines Shoulder and Edge Line Rumble Strips Pavement Markings Over Rumble Strips Adequate Driver Rest Areas Motorcycle Attenuating Devices "Forgiving" Poles Advanced Warning Signs Traffic-Calming Measures Automated Enforcement Roadside Cable Barriers Wider Longitudinal Pavement Markings Safety Edges
Zhetbai-Zhanaozen			
Taldykorgan-Kalbatau	Single Vehicle Run-off	Speeding	Sign and Pavement Marking Improvements Central Hatching Post-Mounted Delineators and Chevrons Edge Lines Shoulder and Edge Line Rumble Strips Pavement Markings Over Rumble Strips Adequate Driver Rest Areas Motorcycle Attenuating Devices "Forgiving" Poles Advanced Warning Signs Roadside Cable Barriers Wider Longitudinal Pavement Markings Safety Edges Traffic-Calming Measures Speed Displays Automated Enforcement

04

Conclusion

By continuing to improve its roads, Kazakhstan can become a leader for connectivity and road safety in Central Asia. This study highlighted areas where further work will help achieve those twin goals and recommended specific infrastructure improvements. The analytical results and recommendations can be updated as additional data becomes available. Working with international institutions, Kazakhstan has been building its capacity in these areas. Those efforts could become even more important in the future as new trade routes emerge between Asia and Europe and as incomes and motorization rates within Kazakhstan rise. As the region changes, building and managing safe roads will remain a wise investment.

Appendix A. CAREC Routes

Table 3. CAREC Routes, 2015

Road Segment	Length (km)	Avg. Annual Daily Traffic (AADT) 2015	Cross Section	Horizontal Geometry	Vertical Geometry	Proposed Improvements
Karaganda-Burylbaital-Kurty	888	8,700	Two-lane two-way Soft shoulders	Essentially straight Some short and large radii curves	Runs across cross-country terrain and flatland Some steep grades (more than 5%) for 4% of total length	Four-lane two-way divided 90 bridges, overhead crossings and traffic interchanges
Taldykorgan-Kalbatau	662	2,792	Two-lane two-way Soft shoulders	Essentially straight Numerous large radii curves	Runs across cross-country terrain and flatland Some steep grades (more than 5%) for 5% of total length	Four-lane two-way divided, and two-lane Dangerous curves straightening 74 bridges, overhead crossings, and traffic interchanges
Atyrau-Astrakhan	277	4,674	Two-lane two-way Soft shoulders	Essentially straight Some short and large radii curves	Runs across cross-country terrain and flatland Some steep grades (more than 5%) for 2% of total length	Two-lane with dangerous curves straightening 34 bridges, overhead crossings, and traffic interchanges
Uzynagash-Otar	96	6,061	Two-lane two-way Soft shoulders	Essentially straight Some large radii curves	Runs across cross-country terrain and flatland No steep grades	Four-lane two-way divided 13 bridges, overhead crossings, and traffic interchanges
Beyneu-Akjigit	84	1,138	Two-lane two-way Soft shoulders	Essentially straight	Runs across flatland No steep grades	Two-lane with dangerous curves straightening
Zhetybai-Zhanaozen	73	5,460	NA	Essentially straight Some large radii curves	Runs across cross-country terrain and flatland No steep grades	Four-lane two-way divided, and two-lane Dangerous curves straightening 3 overhead crossings and traffic interchanges

Appendix B. Crash Calculations

The following equation was used to calculate crash rate per roadway kilometer of the AHN in 2010 (see pages 7–8):

$$R = \frac{C}{N * L}$$

where

R = crashes per kilometer for the road segment expressed as crashes per one kilometer of roadway per year

C = total number of crashes in study period

N = number of years of data

L = length of the roadway segment in kilometers

This method does not account for traffic volume. Instead, the length of the roadway is used as the measure of exposure.

Applying a similar method, a fatality-per-kilometer rate for the AHN in 2010 was calculated using the following equation (see pages 10–11):

$$R = \frac{D}{N * L}$$

where

R = fatalities per kilometer for the road segment expressed as deaths per one kilometer of roadway per year

D = total number of fatalities in study period

N = number of years of data

L = length of the roadway segment in kilometers

Using the following equation, a “critical crash rate per road segment” was calculated for CAREC routes in 2015 (see page 8):

$$C_c = C_a + C \sqrt{\frac{C_a}{M}} + \frac{1}{2M}$$

where

C_c = critical crash rate

C_a = average crash rate

C = assuming a 99.5 percent level of confidence (where $C = 2.576$)

M = 100-million vehicle-miles exposure

Hence, the following equation is used to find the 100-million vehicle-miles exposure:

$$MVM = \frac{AADT * L * t * 365}{100,000,000}$$

where

L = segment length in kilometers

T = time period (in this case, t is 1 year, focusing the analysis on a base case AADT scenario for one year)

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