Decision analysis for transporting critically ill patients with cardiovascular diseases

by

Yerbolat Kalpakov

Submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Mechanical Engineering

School of Engineering and Digital Sciences
Department of Mechanical and Aerospace Engineering
Nazarbayev University

Supervised by

Assistant Professor Yerkin Abdildin (Lead Supervisor)

Assistant Professor Dmitriy Viderman (Internal Co-Supervisor)

Professor Ali E. Abbas (External Supervisor, University of Southern California, USA)

November, 2025

Declaration

I certify that, with the exception of correctly referenced quotes and references, the manuscript "*Decision analysis for transporting critically ill patients with cardiovascular diseases*" is entirely my original work. I further affirm that, to the best of my knowledge, no other academic degree at Nazarbayev University or elsewhere has accepted this work in whole or in part.

Name: Yerbolat Kalpakov

Data: November 2025

Abstract

The transportation of critically ill patients with cardiovascular diseases is a critical aspect of emergency medical care, particularly in countries with vast territories, dispersed populations, and centralized healthcare services. In Kazakhstan, where specialized cardiac centers are concentrated in major urban areas, the need to transfer patients across long distances presents a complex decision-making problem that intertwines logistical, clinical, and economic challenges. Selecting the most appropriate mode of transport whether by airplane, helicopter, ambulance, train, or private clinical vehicle requires a careful evaluation of trade-offs between cost efficiency, transportation time, and patient safety during transit.

This dissertation addresses this multifaceted problem by applying a rigorous decision-analytic framework grounded in Multiattribute Utility Theory (MAUT). The methodological contribution of this research lies in the development and application of a multiattribute utility function, $U(X_1, X_2, X_3)$, which incorporates three key attributes: transportation cost savings (X_1), time savings (X_2), and the medical impact of transportation on the patient's health status (X_3). The widely used APACHE II scoring system is used to measure how sick a patient is, which gives a more complete and accurate picture of their health than the color-based triage system that is currently used in Kazakhstan.

We got our data from official sources, like the National Coordination Centre for Emergency Medicine (NCCEM), and we also got structured expert input from experienced medical professionals, such as an anesthesiologist who is familiar with transporting high-risk patients. The results show that the decision maker's preferences are not utility independent across the three attributes. This insight led to the construction of a utility function under partial utility independence (PUI) condition, using a functional form derived from the Utility Dependence Matrix (UDM) and elicited through certainty equivalent methods.

The resulting analysis produced a ranking of the transportation alternatives under the PUI framework: airplane (1st), helicopter (2nd), ambulance (3rd), private clinical cars (4th), and train (5th). Further comparison was conducted using a multilinear utility function assuming complete utility independence and a series of single-attribute evaluations. These comparative analyses demonstrated the sensitivity of rankings to assumptions about attribute independence and underscored the value of employing a nuanced, realistic representation of decision maker's preferences in high-stakes healthcare contexts.

This study contributes to both the theoretical and applied domains of decision analysis. It offers a novel decision-support model tailored to the healthcare landscape of Kazakhstan, while also serving as a replicable framework for other nations facing similar geographical and infrastructural constraints. Ultimately, the proposed model enhances the objectivity and transparency of transport decision-making, supporting policymakers and emergency coordinators in their efforts to deliver timely, cost-effective, and clinically appropriate care to the most vulnerable patient populations.

Acknowledgements

I would like to express my deepest gratitude to my supervisors Professor Yerkin G. Abdildin, Professor Dmitriy Viderman and Professor Ali E. Abbas for their invaluable guidance, encouragement, and support throughout this journey. Their expertise and mentorship have been instrumental in shaping the direction and completion of this dissertation.

To my parents, I owe an immeasurable debt of gratitude. My father and mother have been the unwavering pillars of my life, whose love, wisdom, and sacrifices have laid the foundation for every step of my journey. Their constant support, from the very beginning of my education to the hardest times in this academic pursuit, has always given me strength and motivation. They taught me to be honest, humble, and never give up, which have all helped me get through this whole thing. If they hadn't believed in me and helped me all the time, this goal would have stayed a dream.

I love and value my wife and kids very much. Thank you, wife, for being patient with me during all those long nights and for always cheering me on, even when things were hard. Your quiet strength and support over time have been a guiding light. To my children, your smiles, laughter, and innocent joy have given me strength in moments of doubt and exhaustion. You reminded me of my purpose and inspired me to keep moving forward. This accomplishment is as much yours as it is mine, for it was built on your love, understanding, and sacrifice. Special thanks to Dean of School of Engineering and Digital Sciences Professor Elizabeth Arkhangelsky, for providing me with teaching assistantships, which were both a financial support and the opportunity to perfect my teaching skills.

I thank proficient staff members in the Department of Mechanical and Aerospace Engineering: Professor Essam Shehab, Associate Professor Md. Hazrat Ali, Associate Professor Basman Elhadidi, Assistant Professor Sherif Gouda, Assistant Professor Gulnur Kalimuldina, Associate Professor Konstantinos Kostas, Associate Professor Asma Perveen, Assistant Professor Yerbol Sarbassov, Instructor Dmitry Sizov, Associate Professor Didier Talamona, Assistant Professor Altay Zhakatayev, and Professor Yong Zhao.

It has been a pleasure to study at Nazarbayev University, meet phenomenal students and genius individuals from around the world, and great groupmates: Nursultan Alzhanov, Aigul Nagimova and Olzhas Mukhmetov.

I thank my friends Margulan Zharkenov, Alibek Orynbek, Olzhas Shaiken, Batyrkhan Orazbayev, Mustafa Shambulov, Abay Zhussupov, Aibol Zairbek, Yerkebulan Assamidanov, Yersin Korganbek, Meirgali Mussulmanbay, Olzhas Agubayev, Almas Ibrayev, Nurzhan Abeuov, Azamat Shakharov, Yerkebulan Nyssanbayev, Mukagali Beisenbayev, Nursultan Abiev, Assylbek Meirambek, Nurbolat Igibayev, Samat Smakov, Yerlan Ayash, Sabi Zhanabayev, Renat Saifullin, Yerzhan Omarov, Ulykbek Shambulov, Raim Khamzin, Dauren Nurgmaganbetov, Maxat Istayev, Serik Aidarbekov, Adilbek Tussipali, Nursultan Sadyk, Nurzhan Khamze, Yeldos Birmaganbetov, Aslan Medebayev, Alibek Tussenov, Alisher Suyunzhanov, Aset Tulyubekov Sergey Zhuravlev, Margulan Moldabekov, Ilyas Shoman, Yerzhan Shaiev, for being with me during a lifelong learning journey.

I also thank my Librarian friends Nurbek Abdollayev, Zhandos Mussabekov, Yerlan Korganbek, Yerkebulan Tlemissov, Olzhas Ismagambetov, Rustem Toktarov, Nurlan Bagibayev, Sultan Otegenov, Beknur Abitayev, Nurdaulen Dosmagambet, Azamat Umirov, and Zhansultan Nurmukhanov who helped me with various activities and also made my life joyful while I was studying in the UK.

I extend my sincere thanks to the professors and instructors at Nazarbayev University for providing a robust academic foundation and inspiring me throughout my studies. I also want to thank the research assistants (RAs) and teaching assistants (TAs) who have helped me have a better academic experience.

Finally, I want to thank Nazarbayev University from the bottom of my heart for making the school a fun and interesting place to learn. University has been more than just a school; it's been a place to grow, face challenges, and learn new things. I'm very grateful for the world-class resources, cutting-edge research facilities, and helpful academic community that helped me do this research. The encouragement of critical thinking, interdisciplinary collaboration, and academic rigor at Nazarbayev University has significantly shaped my scholarly perspective and strengthened the quality of my work. Without the guidance of esteemed faculty members, the availability of scholarly tools, and the university’s commitment to academic excellence, the completion of this dissertation would not have been possible.

List of abbreviations

DA – Decision Analysis

MAU function – Multiattribute utility function

CVD – cardiovascular disease

WHO – World Health Organization

NCCEM – National Coordination Centre of Emergency Medicine

KTZh – JSC National Company Kazakhstan Temir Zholy

APACHE II - Acute Physiology and Chronic Health Evaluation II

UI – Utility independence

PUI – Partial utility independence

UDM – Utility dependence matrix

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Chapter 1: Introduction

1.1 Background

Cardiovascular diseases (CVDs) represent the primary cause of mortality globally, responsible for approximately 17.9 million deaths annually, equating to nearly 32% of all deaths worldwide (WHO, 2021). They encompass various pathologies, including coronary artery disease, stroke, hypertensive heart disease, and congestive heart failure. These diseases pose significant burdens to public health systems due to their chronic nature and the acute exacerbations that require urgent and specialized medical care (Mitchell, 2023). Timely management and intervention are critical determinants of patient outcomes, particularly in emergency situations involving acute cardiovascular events (Khan et al., 2021).

The management of critically ill patients with cardiovascular complications necessitates prompt transport to specialized healthcare facilities equipped to offer advanced diagnostic and therapeutic interventions. Delays in reaching these facilities substantially increase morbidity and mortality rates (Wallace & Ridley, 1999). This challenge is magnified in large geographical areas, especially countries with significant rural populations and dispersed healthcare facilities. Kazakhstan is a good example of this because it has a large land area (2.72 million square kilometers) and most of its healthcare resources are in cities like Astana and Almaty (Shynar et al., 2024).

Kazakhstan's transportation logistics is very difficult because the country is so big, there are not many roads or railroads, and the weather changes a lot. Airplanes, helicopters, ambulances, trains, and clinical cars are all ways to move very sick people to where they need to go. When it comes to cost-effectiveness, speed, availability, and safety, each mode has its own pros and cons. This makes it harder for healthcare logistics to make decisions (Van Lieshout et al., 2008).

Flying, whether in fixed-wing planes or helicopters, is quick and effective, especially over long distances. But they cannot be used all the time because there are not enough resources, the weather may be unsuitable for flying, and the costs of running them are high. Helicopters are better for rural and remote areas because they are more flexible, but also more expensive and dangerous, because they are harder to operate (Zirpe et al., 2023). Fixed-wing planes are better for longer routes that already have airports.

Ground ambulances are a very useful service, especially for short distances, because they are cheap and easy to get. But they do not work as well over long distances because it takes longer to get there and there is a higher risk of patient instability. The quality of the roads also has a big impact on how well ambulances work. Kazakhstan is the 107th safest place in the world for driving. It has a lot of problems with high accident rates and bad rural roads, which make getting around even harder (Smailov, 2022).

People do not use trains very often, but they can be very helpful when the weather is bad or when other ways to get around are not available. Trains are slower, but they are more stable, which can be good for taking care of patients. But their schedules and the infrastructure they use limit them. Clinical cars, which are often used as private transportation, are another option that could work, but are also risky because they do not have enough medical support and equipment, which could put patients' safety at risk.

It is also important for the healthcare system to be able to safely move patients who are very sick. Kazakhstan now uses a triage-based scoring system to put patients into green, yellow, and red zones based on how urgent their medical needs are. On the other hand, the triage system does not do a very good job of predicting when a patient's condition will get worse. We need to use scoring systems that are more complete and accurate, like APACHE II (Acute Physiology and Chronic Health Evaluation II). It is known around the world for being good at predicting how sick patients will do (Knaus, 1985).

1.2 Problem Statement

Taking critically ill patients with heart diseases to the hospital is a difficult logistical and clinical problem that has a big effect on how well patients do and how long they live. When making decisions about transporting patients, you need to think about a number of things, such as cost, time, and patient safety. In Kazakhstan, most decisions are made informally without any clear analytical frameworks, which often leads to less than ideal results (Van Lieshout et al., 2008).

The National Coordination Center for Emergency Medicine (NCCEM) now makes decisions based on simple and often subjective evaluations that do not always include important criteria for making decisions. This way of doing things leads to less than ideal resource allocation, longer wait times for patients to be transported, and a higher chance of bad health consequences. Decision makers often have a hard time balancing keeping costs down, getting patients to their appointments faster, and making sure they stay stable while being transported (Khan et al., 2021).

One big problem is that transportation logistics and clinical risk assessment systems do not work together. Kazakhstan now uses basic triage systems that don't adequately show how a patient's condition changes while they are being transported. The present triage categories (red, yellow, and green) do not take into consideration the small differences in patients' states and don't give any hints about what would happen to them. So, to make decisions more accurately, we need to use more predictive clinical evaluation methods like the APACHE II score system (Knaus, 1985).

Also, changes in the availability of transportation make it harder to make decisions. Lack of resources typically means that people have to wait longer for air or land transit, which might make their situations worse. There is a big gap in formal analytical tools that bring together different aspects of transportation options into a single framework for making decisions. Most of the time, decision-support tools just look at one element at a time and do not take into account how factors like cost, time, and clinical safety affect each other. This mistake causes decisions to be made in a way that is not the best and is broken apart (Abbas, 2018).

We need to create and use a structured, multiattribute decision analytic framework to systematically choose and assess transportation modalities for critically ill cardiovascular patients. A framework should include relevant features, use detailed clinical grading systems, and show how different choice of attributes depend on each other and how they might be traded off. This study addresses a gap by using multiattribute utility theory (MAU) and partial utility independence criteria to create a decision-making model that makes healthcare transportation logistics better and helps patients get well.

1.3 Research Objectives

The overall goal of this dissertation is to develop and apply a defensible decision analysis framework, using multiattribute utility (MAU) theory, to evaluate the transportation options for critically ill cardiovascular patients. The objectives of this research are:

1. **Developing a Comprehensive Multiattribute Decision Framework:** Develop and validate a multiattribute utility function (MAU), including critical transportation attributes: cost savings, saving time on transportation, and patient health safety based on the APACHE II scoring system.
2. **Evaluating Alternative Transportation Modes:** Assess the relative outcomes of airplanes, helicopters, ambulances, trains, and clinical vehicles using quantitative multiattribute utility analysis.
3. **Comparative Analysis of Utility Independence and Partial Utility Independence Conditions:** Examine the differences in outcomes under utility independence (UI) and partial utility independence (PUI) assumptions that are more reflective of actual decision-maker preferences.
4. **Formulating Practical Recommendations:** Provide recommendations for healthcare policy makers for the good use of evidence to achieve better transportation decision making and positive patient effects.

1.4 Significance of the Study

This study fills in important gaps in the theory and practice of decision analysis and healthcare logistics. This dissertation adds to the theory by looking at how multiattribute utility theory is used in the specific case of emergency medical transportation using true preferences of decision maker. This study uses multiattribute utility theory to add to what we know about how complicated decision makers' preferences can be in real life.

The study has important real-world effects on healthcare logistics in Kazakhstan and other countries with similar geographic problems. If important decision-making factors are included in a structured framework, healthcare professionals and policymakers will have a scientifically sound tool to help them make important decisions when moving critically ill patients. The goal of the model created here is to lower health risks linked to patient transport, keep costs down, and speed up transportation by focusing on patient outcomes through quantitative assessment.

This study also uses the APACHE II clinical scoring system, which is used all over the world, as part of the decision-making process for transportation logistics. Kazakhstan's practices are brought in line with international standards by replacing less accurate systems, like color-based triage, with a scientifically validated scoring method. This makes decisions more accurate and health-risk assessments more reliable (Knaus, 1985).

The expected impact goes beyond Kazakhstan. It provides a flexible and scalable model that can be used in healthcare systems around the world that are dealing with similar logistical problems. This dissertation aims to improve global healthcare logistics by providing methodological rigor and useful insights. This will lead to better clinical outcomes and higher patient survival rates.

1.5 Structure of the Thesis

This dissertation is broken up into six chapters, each of which builds on the one before it in a logical way. The goal is to create a complete decision analysis framework for moving critically ill cardiovascular patients. The structure shows both the theoretical basis and the real-world use of multiattribute utility theory (MAUT) in healthcare.

Chapter 1: Introduction discusses the problem's background and urgency. It also talks about the clinical and logistical problems that come up when moving critically ill patients across Kazakhstan's large territory. The problem statement, research goals, and study significance are all given. This sets the stage for the methodological and analytical discussions that will follow in later chapters.

Chapter 2: Literature Review gives a critical synthesis of the research on cardiovascular diseases, emergency patient transportation, and decision-making frameworks. It looks at transport policies, available modes of transport, and operational problems after looking at trends in cardiovascular morbidity and mortality in Kazakhstan and around the world. The chapter also looks at the current triage systems and suggests the APACHE II scoring system as a better option. It then considers the theoretical aspects of multiattribute decision-making and trade-offs, with respect to transport decisions.

Chapter 3: Methodology shows the main analytical framework that was used in this study. There are three cases: partial utility independence (PUI), utility independence (UI), and single-attribute evaluation. This chapter talks about how the multiattribute utility function was constructed, how expert preferences were found, and how the Utility Dependence Matrix (UDM) was used to show how attributes are related to each other (Abbas, 2010). It also explains the justification for choosing attributes like cost savings, time savings, and patient safety, and outlines the steps to develop, normalize, and compare the various utilities.

Chapter 4: Results of the utility analysis under the three different methodological conditions are presented in this chapter. It shows the ranking of transport options using the multiattribute utility function under PUI after comparing the results of UI and single-attribute evaluations. This chapter's tables and figures show in detail how attribute interdependencies affect decision outcomes and the trade-offs between options.

Chapter 5: Discussion looks at the results in light of the theoretical framework and the effects they will have on healthcare logistics in the real world. It looks at the bigger effects on emergency medical services in Kazakhstan and similar places, judges how important the rankings are, and compares the results to those in the existing literature. The conversation also talks about the possibility of using MAUT-based tools in operational and policy-making situations.

Chapter 6: Conclusion discusses the main findings of the study and how the suggested decision model can be used in real life. It also talks about how the methods used in the study have improved. The study's limitations are critically examined, and suggestions for future research include expanding the model to incorporate more clinical situations. The chapter's conclusion has suggestions for emergency transport coordinators, healthcare administrators, and lawmakers who want to make the best use of resources and improve patient outcomes.

The dissertation also contains a full list of references, appendices with additional data, and a detailed explanation of how expert opinion was elicited. These resources help maintain academic rigor, reproducibility, and openness of research.

Chapter 2 Literature Review

2.1 Cardiovascular Diseases

2.1.1 Cardiovascular Diseases (CVDs)

Cardiovascular diseases (CVDs) are a group of diseases that affect the heart and blood vessels in many different ways. The primary categories include coronary heart disease (CHD), cerebrovascular disease, rheumatic heart disease, peripheral arterial disease, congenital heart disease, deep vein thrombosis, and pulmonary embolism (WHO, 2024b). Among these, coronary artery disease and cerebrovascular disease are the most prevalent, often manifesting as myocardial infarction (heart attack) and stroke, respectively. CVDs are not only the leading cause of death worldwide but also a major contributor to disability and reduced quality of life. According to the WHO (WHO, 2021), CVDs account for an estimated 17.9 million deaths each year, representing approximately 32% of all global deaths. Of these deaths, more than 75% occur in low- and middle-income countries, emphasizing the global health disparity in prevention and treatment efforts.

A common feature underlying many cardiovascular conditions is atherosclerosis – a pathological process involving the buildup of plaques composed of cholesterol, fatty substances, cellular waste products, calcium, and fibrin on the inner walls of arteries. This process can begin in childhood and progress silently over decades before manifesting clinically as angina, myocardial infarction, or stroke (Libby, 2021). Hypertension (high blood pressure), dyslipidemia (abnormal cholesterol levels), diabetes mellitus, tobacco use, sedentary lifestyle, unhealthy diet, and excessive alcohol consumption are the primary modifiable risk factors for CVDs (Mensah et al., 2019). In contrast, age, sex, family history, and genetic predisposition are non-modifiable risk contributors.

The pathophysiological mechanisms of CVDs are multifactorial, involving endothelial dysfunction, inflammatory processes, oxidative stress, and thrombosis (Madjid et al., 2020). These mechanisms vary slightly depending on the specific disease but are interlinked through the broader process of vascular injury and response to stress. Notably, ischemic heart disease is characterized by restricted blood supply to the myocardium due to narrowed coronary arteries, whereas stroke is often caused by cerebral artery occlusion (ischemic stroke) or rupture (hemorrhagic stroke).

Public health initiatives over the last few decades have contributed to a modest decline in age-standardized CVD mortality rates in many high-income countries, largely due to better management of risk factors and improved emergency and chronic care (Roth et al., 2020). The number of CVD cases and deaths around the world keeps going up, though, because cities are growing and people are getting older, which makes them more likely to be exposed to behavioral risk factors. In the next few decades, global cardiovascular health will face big problems, especially because more and more young people in both developed and developing countries are becoming obese and diabetic (Zhou et al., 2017).

The burden of cardiovascular disease (CVD) is not distributed evenly around the globe. While high-income countries are often equipped with structured health systems that have access to advanced diagnostics, therapeutics, and preventive interventions, low- and middle-income countries will often lack adequate health systems, health professionals, and awareness campaigns, making delays in diagnostic processes, under-treatment, or the case fatality rate higher (Murray et al., 2020). In addition, socio-economic inequalities, educational level, and health literacy are considerably impactful on cardiovascular outcomes, resulting in worse outcomes for vulnerable populations (Benjamin et al., 2019).

An emerging area of concern with cardiovascular medicine is the intersection of infectious disease and CVD. For example, individuals with pre-existing cardiovascular disease had a greater effect of the COVID-19 pandemic, evidenced by greater morbidity and mortality for those with CVD as compared to prior to COVID-19 (Murray et al., 2020). This emphasizes the systemic vulnerability effect associated with CVD and demonstrates the need for integrated care models that straddle chronic care and acute care.

In conclusion, with their high rates of mortality, complex pathophysiology, and potency as a burden on the global economy, cardiovascular diseases (CVDs) are an important public health topic. Combating CVDs as a burden requires collaborative approaches which include preventative care, health literacy education, legislative/policy advancements, and equitable service delivery. As the world continues to urbanize and the population continues to age, it becomes essential to develop innovative risk management techniques that include novel risk stratification pathways, predictive models for developers and policy analysts, and decision analyses to assess potential returns on the public purse spent on preventing CVDs.

2.1.2 Statistical Data from the World Health Organization

Cardiovascular diseases (CVDs) are still the number one cause of death and a major portion of the global burden reported by WHO (WHO, 2021). Currently, about 17.9 million people die every year from CVDs, and it represents 32% of all global deaths (WHO, 2021). Among these deaths, 85% are due to heart attacks and strokes, two of the most common manifestations of advanced atherosclerotic cardiovascular disease. This statistical reality reflects both the widespread nature and the lethal outcomes of these conditions if not prevented or treated in a timely manner.

In the WHO European Region alone, CVDs are responsible for over 42.5% of all deaths annually, translating to more than 10,000 lives lost every single day (WHO, 2024a). These numbers are particularly alarming considering that a large proportion of these deaths are considered preventable through early intervention, improved lifestyle choices, and access to quality healthcare. Men are more frequently affected than women, though post-menopausal women experience a sharply increasing risk due to the loss of estrogen’s protective cardiovascular effects (Humphries et al., 2017).

Globally, more than three-quarters of CVD deaths occur in low - and middle-income countries, emphasizing socioeconomic disparities in prevention, diagnosis, and treatment (WHO, 2021). These nations often lack the infrastructure for early detection and sustained management of risk factors such as hypertension, high cholesterol, and diabetes. Consequently, patients tend to seek medical help in advanced stages of disease when complications such as heart failure, stroke, or sudden cardiac death have already developed.

Furthermore, the burden of CVD is not only measured by mortality but also by morbidity. It remains a leading cause of disability-adjusted life years (DALYs) lost globally. According to the

Global Health Estimates from the WHO, ischemic heart disease was the top cause of DALYs among adults aged 50 years and older in 2019 (WHO, 2020). Stroke also ranks among the top ten global causes of disability, particularly in aging populations. This double burden of mortality and morbidity places immense pressure on national healthcare budgets, especially in countries where health systems are under-resourced.

The WHO has also noted that high blood pressure is the single most significant risk factor for CVDs globally, affecting an estimated 1.28 billion adults aged 30 - 79 years, with a majority living in low- and middle-income countries (WHO, 2023). Despite being both detectable and treatable, nearly half of these individuals are unaware they have the condition, and only about one in five have it under control. These statistics underscore the critical need for population-based health interventions, such as national screening programs and primary care education, to combat undiagnosed and untreated hypertension.

In terms of trends, while high-income countries have seen a decline in age-standardized CVD mortality rates over the last two decades due to better control of risk factors and improved healthcare delivery, absolute numbers remain high due to aging populations (Roth et al., 2020). On the flip side, many low-to-middle income countries are in the midst of an epidemiological transition where they are experiencing a decline in infectious disease, while at the same time non-communicable diseases (NCDs) - CVDs included - are also rising sharply due to urbanization, lifestyle choices, and poor health literacy.

In response to the continuing crisis, WHO implemented the Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013 - 2020 to reduce premature deaths from non-communicable diseases, including CVDs, by 25% by 2025 (World Health Organization, 2013). The Global Action Plan of 2013 includes nine non-binding global targets such as the global adult tobacco use target, alcohol intake target, access to essential medicines and technologies, etc.

In summary, the global context of cardiovascular disease statistics provided by the WHO raises serious concerns about a continuing and new global health crisis. Although some areas have made progress, the misalignment between risk, treatment access, and outcomes needs urgent attention. International cooperation, stronger health systems, and more advocacy for public health are key to alleviating the global burden of cardiovascular disease.

2.1.3 Kazakhstani Statistical Data

CVDs are the leading cause of morbidity and mortality in Kazakhstan, as with many other parts of the world, except with a national dimension requiring further investigation. The burden of CVDs has dramatically increased over the last twenty years, officially classified as a significant public health crisis for the country's health care system. Epidemiological evidence shows that from 2013 to 2020, Kazakhstan experienced a 40% growth in the overall incidence of diseases of the circulatory system (Junusbekova et al., 2023). This increase is reflective of improvements in surveillance and diagnostic reporting, in addition to an underlying increase in incidence created by an aging population, urbanization, and health-related lifestyle challenges.

The prevalence of arterial hypertension, the primary risk factor for most forms of CVD, has increased at alarming rates. The primary incidence of hypertension in Kazakhstan was reported to be 1.8 times higher during the 2013–2020 period (Junusbekova et al., 2023). This trend has been blamed on a lot of stress, changes in diet, not getting enough exercise, and both patients and providers not following treatment recommendations. Many people, especially those who live in rural or underserved areas, do not know about their condition because they do not have access to primary healthcare or regular screenings.

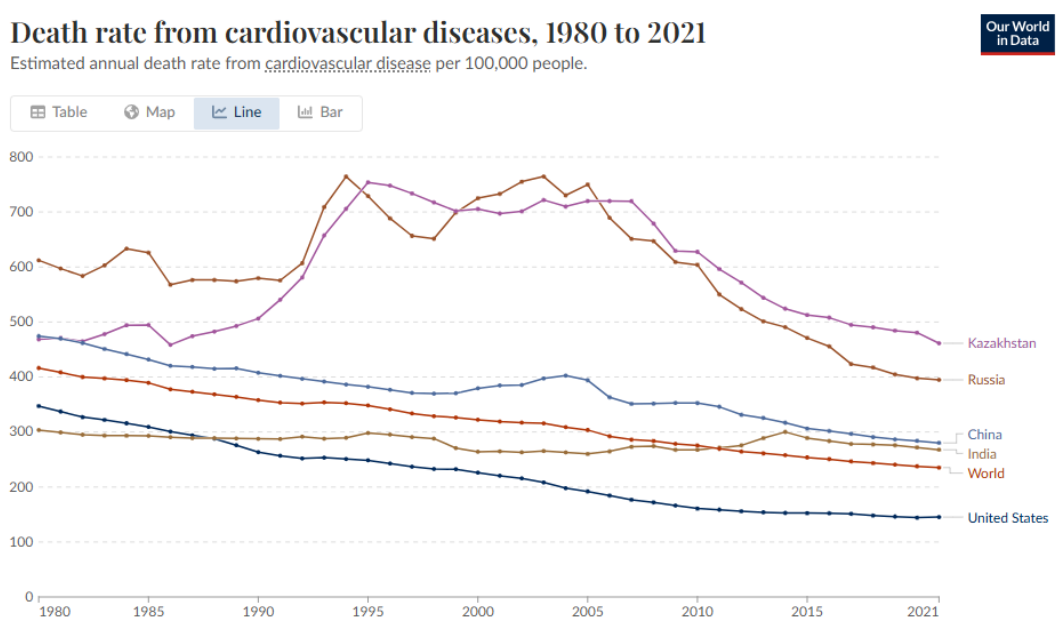


Figure 1 Death rate from CVD, 1980 to 2021 (adapted from https://ourworldindata.org/)

Heart failure and ischemic heart disease are the two conditions that cause the most cardiovascular diseases and deaths in the United States. Between 2014 and 2019, 526,766 individuals were hospitalized due to heart failure (HF) in Kazakhstan, with women representing 54% and men 46% of the group. Of these patients, 457,179 (87%) were aged over 50, and most (61%) lived in urban areas. The cohort exhibited multiple comorbidities, with the following prevalence: hypertension (46%), cardiovascular disease (32%), arteriosclerotic heart disease (23%), acute myocardial infarction (21%), diabetes mellitus (17%), chronic kidney disease (18%), chronic obstructive pulmonary disease (11%), and obesity (7%) (Zhakhina, 2025).

According to (EMCRK, 2025), 31399 cases have been treated by National Coordination center from 2012 to 2022, and 4766 cases were related to CVDs.

Table 1. Categories and number of cases between 2012 and 2022

Category	Number of Cases
Pediatric pathology	7,534
Emergency conditions in obstetric practice	5,392
Cardiovascular diseases	4,766
Neonatal pathology	4,420
Injuries, accidents, and poisonings	3,647
Road traffic accident victims	2,495
Patients with other pathologies	3,145
Total	**31,399**

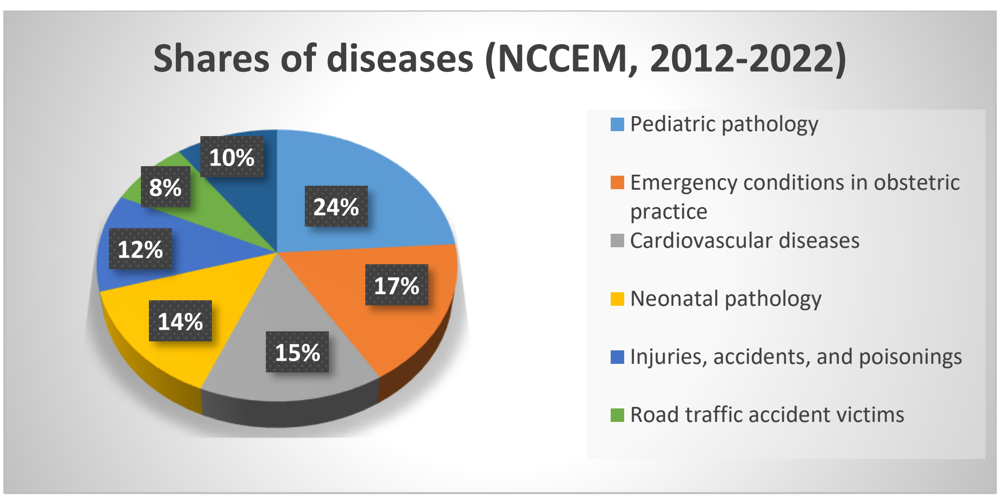


Figure 2 Shares of diseases (EMCRK, 2025)

Data on mortality rates were collected from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (Mukasheva et al., 2022), and included: population for age categories in the Republic of Kazakhstan; mortality due to CVD by gender and mortality due to CVD from 2011 to 2021 was reported for 5-year age groups (0, 1-4, 5-9, 10-14, 70-74). The causes of death in the population were classified, based on the 10th revision of the International Classification of Diseases, ICD 10: Chronic rheumatic heart disease (I05-I09); Hypertensive diseases (I10-I15); Ischaemic heart disease (I20-I25), and Cerebrovascular diseases (I60-I69). Death rates back up how serious the problem is even more. According to the Kazakhstan National Statistics Bureau (Mukasheva et al., 2022), ischemic heart disease and cerebrovascular accidents were the most common types of CVDs in 2021, causing about 47% of all recorded deaths. There are still differences between regions, though. Higher CVD death rates are seen in northern and central oblasts (regions), where older populations, poor healthcare infrastructure, and worse environmental conditions make the risk higher. On the other hand, bigger cities like Astana and Almaty have more specialized cardiovascular centers and the newest ways to diagnose and treat heart problems.

There are a number of national programs in place to deal with this problem. The "Salamatty Kazakhstan" and "Densaulyk" state healthcare development programs from 2011 to 2020 put a lot of emphasis on screening adults over 40 for high blood pressure, finding CVDs early, and running public awareness campaigns to get people to change their lifestyles (Shynar et al., 2024). Even with these efforts, there are still problems, mostly because there are not enough staff, the implementation is not consistent across regions, and primary care and tertiary cardiovascular services are not working together. Recent studies also suggest that Kazakhstan may have trouble with secondary prevention. Patients with a CVD diagnosis still do not take their antihypertensive, lipid-lowering, and antiplatelet medications as often as they should (Glushkova et al., 2023). This situation leads to repeated hospital stays, complications that could have been avoided, and higher costs for the healthcare system.

Kazakhstan's out-of-pocket medical costs are still relatively high, according to data from the World Bank and the World Health Organization. This makes it hard for people with chronic illnesses who need ongoing care and monitoring to pay for it. Pensioners and people who live in rural areas, who often get little help from the government, have an even bigger burden (Shaltynov et al., 2024).

In conclusion, Kazakhstan has a serious public health problem because CVDs are becoming more common, hypertension rates are rising, and deaths and DALY losses are high. Even though national programs have shown a commitment to solving these issues, more needs to be done to ensure fair access, support primary care, and improve long-term disease management. By strategically combining data-driven decision-making with global best practices, the country may be able to lower its rising cardiovascular burden.

2.2 Transporting critically ill patients

2.2.1 Policy (Transport or Not to Transport)

There are many factors that go into the decision to move critically ill patients, especially those with cardiovascular diseases (CVDs). These include clinical judgement, institutional protocols, resource availability, and ethical considerations. This choice is based on a simple risk-benefit analysis: does moving a patient who is physiologically unstable pose more risks than the possible benefits of getting cutting-edge medical care at a specialized facility? (Droogh et al., 2015). This sub-chapter looks at the frameworks and policies that currently govern transport choices both internationally and in Kazakhstan. It does this by focusing on the standards, procedures, and real-world limitations that affect those choices.

In modern intensive care and emergency medicine, moving very sick patients is usually called intrafacility (between hospitals) or interfacility (within the same institution). When local hospitals cannot provide the specialized staff or technical skills needed to treat complicated heart problems like refractory arrhythmias, acute myocardial infarction that needs percutaneous coronary intervention (PCI), or cardiogenic shock that needs mechanical circulatory support, interfacility transport is most often used (Kue et al., 2011a). However, the act of transportation can exacerbate a patient's clinical condition due to factors such as hemodynamic instability, interruptions in treatment, limited monitoring during transit, and environmental stresses including vibration, noise, and temperature changes.

Most international guidelines, such as those issued by the European Society of Intensive Care Medicine and the Society of Critical Care Medicine (SCCM), recommend that the decision to transport must be grounded in a multidisciplinary discussion involving the referring physician, receiving specialist, transport team leader, and sometimes the patient or family (Fanara et al., 2010). Pre-transport stabilization is a key principle, involving the correction of hypotension, hypoxia, electrolyte imbalance, and arrhythmias before any movement is attempted (Wiegersma et al., 2011). Moreover, an appropriately equipped and staffed transport vehicle - whether ground ambulance, helicopter, or fixed-wing aircraft - is essential for minimizing adverse events en route.

In Kazakhstan, the national health system has introduced clinical protocols for emergency medical services (EMS), which emphasize strict criteria for determining eligibility for transport (Adilet, 2020). According to these protocols, patients in critical condition may only be transported if they are deemed "transportable," defined as those whose vital parameters can be maintained within acceptable limits during transit. Triage decisions are supported by risk scores and physician assessment, and transportation is typically avoided if the patient is in terminal stages of illness or if the transportation risks outweigh potential clinical benefits.

Ethical considerations also play a substantial role. Sometimes, refusing to transport a patient can make people angry, lead to legal action, or make people think you are careless, especially in places with few resources. So, it is important to be able to talk to patients and their families freely and write down why decisions were made. Transport policies also need to be changed to take into account geographical challenges, such as Kazakhstan's large, sparsely populated areas where delays in transport can lead to clinical deterioration (Perzadayeva, 2020).

The adoption of telemedicine and virtual consultations appears to be becoming part of the transport frameworks to supplement decisions made while avoiding immediate transfer of a patient. This is particularly useful in reducing the distance between rural providers and specialists in urban centers, particularly regarding cardiovascular emergencies. The solutions support the opportunity to determine diagnosis and initiate management in an appropriate time frame prior to deciding on transport (Asadi et al., 2024).

In summary, the decision to transfer a patient who is critically ill is a process that needs to be considered many factors including urgency, clinical stability, available transport options, and access to a specialist. Clearly, both international and national guidelines lend themselves towards transfer only occurring when the likelihood of improved outcome is substantial, and only after ensuring appropriate safeguards are in place, with experienced personnel, appropriately equipped vehicles and stabilized patients. For instance, in Kazakhstan, an opportunity may exist to develop and in institutionalize transport protocols and telemedicine applications are promising ways to improve the safety and effectiveness of critical care transport in urban and rural contexts.

2.2.2 Transportation Modes

2.2.2.1 Airplane

Fixed-winged aircraft represented as air ambulances are a crucial part of modern emergency and interfacility medical transport systems today. As it relates to remaining geographically connected with specific patient-care capabilities, fixed-wing air medical transport is very beneficial to patients who have cardiovascular emergencies such as acute myocardial infarction, advanced heart failure, or complication post-cardiac surgery. Patient transfer to tertiary care in the context of air medical transportation can improve clinical outcomes when patients reach specialized care sooner (Sepehrvand et al., 2020).

The key to fixed-wing air medical transport is the advantage of speed and range for long distance and interregional patient transfers. Fixed wing aircraft are fundamentally very fast when operating at high altitudes and can transcend the same geographic lands in a manner that avoids congested roadways and weather conditions in the many local regions that can often have delays in ground patient transport. Such logistical context is important to know as Kazakhstan have most specialized cardiovascular services centralized in two cities, Astana and Almaty. In Kazakhstan, there are large geographic land areas that can be served only by medical transport and where access to specialized care can take too long (Shynar et al., 2024). Patients in remote western or northern Kazakhstan do not have on-demand access to treatment with specialized cardiac catheterization laboratories and have historically used fixed-wing air ambulances to more quickly access a Percutaneous Coronary Intervention (PCI)-capable center.

Air medical transport often has pressurized cabins, high-tech life-support equipment, and medical crews that have been trained specifically for this type of work. According to (Dewhurst et al., 2001) these planes can be made to look like the ventilators, cardiac monitors, infusion pumps, and defibrillators that are used in intensive care units (ICUs). The medical team on board usually includes a critical care doctor or paramedic, a nurse, and sometimes a respiratory therapist. The more complicated the situation, the more people there are. This setup lowers the risk of hemodynamic deterioration or arrhythmia during transport because it allows for ongoing monitoring and intervention. There are, however, some problems with flying. Changes in cabin pressure, noise, vibration, low humidity, and other environmental factors can affect both the patient and the medical equipment. Changes in atmospheric pressure can make symptoms worse or put cardiovascular patients with unstable angina, congestive heart failure, or recent heart surgery at risk of losing their hemodynamic stability (Droogh et al., 2015). Also, fixed-wing planes can only fly in rural or mountainous areas that do not have airports nearby because they need access to the right airstrips and runways. Because of this limitation, ground ambulance coordination is needed at both the departure and destination locations. This could make the transport process take longer and be harder to plan. Cost is another thing to think about. In accordance with (Tavakoli et al., 2022), air ambulance services are expensive and use a lot of resources, often costing thousands of dollars for each transfer. In many countries, including Kazakhstan, the government usually offers these kinds of services for emergencies, but not all patients may have the same access to them.

Despite these ambiguities, international standards and guidelines, including those of the European Society of Cardiology and Association of Air Medical Services, identified fixed-wing aircraft as an essential part of the continuum of critical care transport. Fixed-wing transport requests are best warranted for emergency presentations or time-sensitive interventions, such as ST-elevation myocardial infarction (STEMI) where time must be minimized between door-to-balloon times or regional hospitals breached surge capacity during a mass casualty event (Naser et al., 2016).

In Kazakhstan, under the most recent 2018 health reforms dubbed “Densaulyk” (Public Health) state program, national investments in air medical services included the continued expansion of fixed-wing aircraft specifically designated for critical care transport, with improved access to distant clinics and improved coordination to the national centers (Birtanov, 2017). These investments were designed to address interregional access gaps to advanced cardiovascular care and ultimately optimize outcomes for patients suffering an acute cardiac event outside a major urban center.

In Kazakhstan the emergency ambulance service is managed by the Republican State Enterprise "National Coordination Center for Emergency Medicine" (EMCRK), which is supervised by the Ministry of Healthcare. The emergency ambulance service provides emergency medical care by air transport and to ensure timely access to emergency medical treatment for patients in remote locations.

The air ambulance fleet in EMCRK consists of more than 30 air vehicles, including fixed-wing and helicopters. EMCRK utilizes a medical module fitted on both fixed wing aircraft and helicopters to provide intensive care during transport. The fleet includes Soviet-designed models and Western aviation models, ensuring versatility and adaptability to various terrains and weather conditions.

Air ambulance operations in Kazakhstan encompass several key functions (EMCRK, 2025):

- Patient Transportation: Critically ill patients are transported from regions lacking the necessary medical facilities to specialized centers in cities like Astana and Almaty.
- Specialist Deployment: Medical professionals are flown to remote locations to provide on-site consultations, surgeries, or emergency care.

- Organ and Biomaterial Transport: The service facilitates the rapid movement of donor organs and biological materials essential for transplantation procedures.
- Remote Medical Services: Via telemedicine, specialists can conduct consultations and make medical air evacuation recommendations.

The recommendation to access air ambulance services depends on several factors:

- Accessibility Challenges: Areas with limited or non-existing road access, or natural barriers.
- Medical Resource Inadequacies: Areas available medical facilities have limited equipment or specialists.
- Urgency: Situations when immediate medical care is needed and speed of transport by land is unviable.

To maximize efficiency, each region in Kazakhstan has a designated medical coordinator who can assess the situation and coordinate with the EMCRK to expedite the assessment and dispatch of a medical air evacuation. For example, the service provides between 3 to 15 flights a day to respond to the numerous medical emergencies they receive, which can include acute cardiovascular issues, trauma, and obstetrical crisis.

In conclusion, airplane-based medical transport is very important for moving critically ill cardiovascular patients over long distances. Its high costs, infrastructure needs, and operational complexity make it less useful than its speed and advanced care capabilities. In countries like Kazakhstan with small populations and centralized healthcare systems, strategic integration of air ambulance services is necessary to ensure that everyone has equal access to life-saving cardiovascular interventions.

2.2.2.2 Helicopter

Helicopter Emergency Medical Services (HEMS) are an important part of modern emergency care systems because they can quickly take patients who are very sick or hurt to the right kind of care. Helicopters are better for short distances and emergencies when every second counts for a patient's life. For long distances, fixed-wing planes are better. They are especially helpful in cities that are hard to get to or have a lot of people living there because they can take off and land vertically. Ground ambulances may be delayed by traffic or bad infrastructure (Bledsoe et al., 2006). In cardiovascular emergencies like stroke or acute myocardial infarction, HEMS operations are especially important because getting patients to definitive care faster, known as the "golden hour," can have a big effect on how well they do. Studies have shown that patients with ST-elevation myocardial infarction (STEMI) who are flown by helicopter to places that can do percutaneous coronary intervention (PCI) have shorter door-to-balloon times and higher survival rates than those who are driven there (Galvagno Jr et al., 2015).

Kazakhstan, with its vast territories and low population density in many regions, has recognized the strategic importance of helicopters for delivering emergency medical services. The Ministry of Healthcare runs the National Coordination Centre for Emergency Medicine (EMCRK), which includes helicopter services as part of its larger air medical transport system. Kazakhstan's HEMS will have several Mi-8 helicopters and Eurocopter EC145 units set up for intensive care transport by 2025. These helicopters are stationed in key areas to cut down on response times in emergencies and provide life-saving care in remote villages, mountainous areas, and steppe areas that may not be reachable by road or fixed-wing aircraft (EMCRK, 2025). The helicopters in Kazakhstan's air ambulance system have the most advanced medical equipment, like ventilators, defibrillators, infusion systems, and systems for keeping an eye on patients. The onboard medical teams typically consist of a doctor and a paramedic or nurse; both trained in critical care and emergency response. These teams can start or continue advanced life support and keep heart patients stable while they are on their way to hospitals that are better equipped to help them (Shynar et al., 2024).

Helicopter transport is unique because it can be used quickly in natural disasters and mass casualty events. Helicopters can go to the site of an accident to keep patients stable and take them straight to trauma or cardiac centers, skipping over other hospitals along the way. This system reduces the number of handoffs and possible treatment delays, which is very important for people who have cardiogenic shock or post-resuscitation syndrome after cardiac arrest (Bläsius et al., 2021). There are good and bad things about helicopters. The weather, the amount of light, and the shape of the land all have a big effect on how they work. It can also be harder to care for and talk to patients while flying because of noise, vibration, and lack of space. From an economic point of view, HEMS takes a lot of resources. Helicopter transport should only be used when it is absolutely necessary and only when there are triage protocols and clinical severity scoring systems in place (Krüger et al., 2010). Kazakhstan and a lot of other countries have made it clear what needs to happen for helicopters to be used safely and effectively. These include clinical signs (like a Glasgow Coma Scale score of less than 8 or a systolic blood pressure of less than 90 mmHg), conditions that need to be treated right away (like STEMI or stroke), and logistical issues (like a long travel time on the ground or terrain that is hard to get to). EMCRK has set up similar rules to make sure that helicopters are used fairly and effectively in all areas (EMCRK, 2025).

In short, helicopters are very important for getting people to and from critical care situations, especially when time is of the essence, like in rural outreach and cardiovascular emergencies. In places like Kazakhstan, where distance can make it hard to get specialized care, they are important because they can help fill in the gaps in healthcare delivery systems that are caused by geography and infrastructure. Kazakhstan's HEMS network will work even better if it keeps getting money for training, equipment, and coordination.

2.2.2.3 Ambulance

Ground ambulances are the most common and flexible way to move critically ill people around the world. They are a big part of prehospital emergency services and interfacility transfers because they are easy to get to, cheap, and can be used for many different medical problems. Ground ambulances are a key access point for continuity of care, especially in cases of cardiovascular emergencies where immediate clinical care has been proven to decrease negative patient outcomes (Nielsen et al., 2013). Many emergency services refer to three levels of service for ambulances: Basic Life Support (BLS), Advanced Life Support (ALS), and Critical Care Transport (CCT). BLS ambulances utilize emergency medical technicians (EMTs) and are prudent with non-invasive care modalities, such as providing oxygen or utilizing CPR. Advanced life support units have paramedics providing medical care, AED, cardiac monitoring and intravenous medications. CCT point of care transport is the optimal level of committed ambulance which behaves and functions as an intensive care unit, in situations where this is appropriate. CCT units utilize either physicians or nurses who are credentialed in critical care, and are equipped with ventilators, infusion pumps and/or invasive monitoring devices (Singletary et al., 2020).

In cardiovascular emergencies - acute myocardial infarction, heart failure, and severe arrhythmias - the majority of these patients will be transported by CCT and ALS ambulances and completed prehospital stabilization of medications such as nitrates or beta blockers along with cardiac rhythm strip monitoring and coordination of the receiving hospital and verifying they are ready for immediate care on the patients arrival (Terkelsen et al., 2010). Completing prehospital interventions can expedite patient treatment times like door to treatment times especially now with multilayer options in STEMI patients for new timeliness at reperfusion treatment via PCI methods.

In Kazakhstan, ambulances are still the main way to medically transport patients when urban and inter-regional transfers occur. The ambulance fleet in Kazakhstan contains three separate types of vehicles that provide different levels of care: Ground and Air Transport are basic transportation vehicles, Mobile Medical Resuscitation Service are coded vehicles on the fleet (Ministry of Healthcare of the Republic of Kazakhstan), (Messova, et al., 2023). These medical transport vehicles can not only be dispersed throughout urban locations but also regional hospitals (depending on ambulatory transfer). Ambulances used in Kazakhstan will be able to be deployed to undertake a protocol driven call supported by a documented time to ensure that the ambulance could efficiently transfer a patient in medical care to the receiving facility in a timely manner. Ambulances in Kazakhstan ended to hold their own emergency tier systems that are at times integrated within the work of the Unified National Dispatching Service (UNDS). Under the UNDS, transport care may be assigned based on case level and marked with distance and available personnel and vehicles, also assessment for the delivery of service (EMCRK, 2025). The purpose of the UNDS was to regulate the time to service across Kazakhstan while adhering to concerns on an integrated basis within an urban region with increased population density (Almaty and Astana).

The top priority regarding ground ambulance transport is the quality of road infrastructure, the range of travel in the desert, especially in the rural areas of Kazakhstan. In bad weather, like snowstorms or very cold weather, response times can be a lot longer. This could be bad for the patient's health. Also, not all ambulances in rural areas are equally prepared to handle serious heart problems. This shows how important it is to update the fleet and make training the same for everyone (Graham et al., 2015). Ground ambulances do have some advantages over other types of ambulances, though. They allow medical staff to keep an eye on the patient while they are being moved, stay in touch with the hospital that will receive them, and make it easy for the patient to get to the emergency room when they arrive. Most of the time, ground transport is less resource-intensive and easier to find than air transport, which makes it the best choice for moving patients (Joseph et al., 2022).

Technological developments have continued to expand the capabilities of ambulances. For example, implementation of telemedicine has allowed paramedics to have real-time conversations with cardiologists at the time of transport, which permits early diagnosis and treatment planning. With the actions of triaging patients or determining interventions, this is of extreme importance. The introduction of GPS tracking and an electronic patient record allows for improved coordination and documents kept in a single view, helping facilitate an improved overall transportation of patients (Thomas et al., 2002).

In summary, ground ambulances have become an integral part of a critical care transport system because of their flexibility and cost-effectiveness, allowing support of responses for a variety of emergencies (cardiovascular events, for example). Challenges remain in certain areas (especially in rural and remote regions), but continued investment in both infrastructure, equipment, and people means that ambulances will continue to be an important link in the chain of survival for critically ill patients in Kazakhstan and around the world.

2.2.2.4 Train

Trains are not as common as other ways to get around, but they have been used to move patients in some places, especially where the roads are bad and the distances are long. Kazakhstan Temir Zholy (KTZ), the country's national railway company, has built a complete railway network that moves people and goods and helps with medical outreach programs. Kazakhstan has one of the biggest railway networks in the world, with about 21,000 kilometers of track. KTZ has operated since 1997 and administers the country’s rail network, which plays a vital part in transportation infrastructure across the country. The railway system enables movement between regional urban centers and geographically remote locations and represents a key transport asset for distribution and logistics operations, as well as contingency operations such as medical evacuation. The upgrade of the rail system to modernize and enhance the overall quality and efficiency of the rail infrastructure has continued. As a result, KTZ has worked under a National Infrastructure Plan for 2029 that includes plans to upgrade approximately 11,000 kilometers of rail sections to improve safety and efficiency levels of operation. By upgrading the railway system, the ontology of transport will encompass all modes of transport on the rail system, including specialized needs such as medical trains.

Kazakhstan has implemented innovative measures to address disparities in access to health care, notably in remote areas of the country. One initiative involves medical trains, which provide health services to underserved groups. Three medical trains ("Densaulyk," "Zhardem," "Salamatty Kazakhstan") have provided diagnostic, therapeutic, and minor surgical services since 2010. The medical trains are well equipped with modern medical equipment and are staffed by an interprofessional health team, which typically includes general and specialized practitioners and nurses. The trains operate on a predetermined schedule and travel to different destinations to provide health services at stations, and ultimately, to the people of the local community. Between 2010 and 2014, medical trains helped more than 56,000 people, which shows how they made healthcare easier to access (Kulkayeva, 2016). The success of these medical trains shows that railroads could be used to deliver healthcare, especially in areas where there are not many traditional medical facilities. These services are not meant for emergency critical care transport, but they are very important for early diagnosis and preventive care, which are both important for managing long-term conditions like heart disease. There are pros and cons to using trains to move patients, even though there are some benefits. Trains are not as fast or flexible as ambulances or planes, so they are not the best way to get to an emergency that needs to be handled quickly. Standard passenger trains also are not made to handle critical care situations, and it would be very expensive to make them work for that purpose. Also, train schedules and routes are set, which can make things take longer in an emergency. Trains can help with healthcare, especially routine and preventive care, but they can't replace faster emergency medical services. In conclusion, trains are a good way to get healthcare to people in Kazakhstan, especially through medical outreach programs that help people who live far away. KTZ's extensive railway network helps these projects get the support they need. Ambulances and air transport are still very important for emergency transport and critical care, though, because they are more flexible and faster. Continued investment in railway infrastructure and medical train services can enhance healthcare accessibility, contributing to improved health outcomes in Kazakhstan's diverse regions.

2.2.2.5 Private clinical cars

Private clinical vehicles, often operated by non-governmental healthcare providers, play a supplementary role in patient transportation, particularly in non-emergency situations or when public emergency services are overburdened. These vehicles are typically used for scheduled interfacility transfers, outpatient appointments, or transporting patients with chronic conditions who require medical supervision during transit.

In many healthcare systems, including Kazakhstan's, private clinical cars serve as an alternative to public ambulance services, especially for patients categorized under lower urgency levels. Most of the time, these vehicles have basic medical equipment and are driven by healthcare professionals who can keep an eye on patients while they are being moved.

Kazakhstan's healthcare system has to deal with some unique problems because the country is so big and its people are spread out. The public ambulance service is very big, but it often does not have enough resources, especially in big cities like Astana. In 2024, a report said that 53 of the 145 ambulances in Astana needed repairs, and 37 were too damaged to be fixed because of accidents (Sariyev, 2024). Because of this lack, 20 teams that were hired from outside the company had to use their own cars to get people to the hospital. The Ministry of Healthcare knew about the problem and said that the city needed 187 teams to handle all kinds of calls. There were plans to deliver up to 70 new ambulances by the end of 2024 and into the first half of 2025 to make up for the lack of them.

Some people have liked the idea of using private clinical cars instead of regular ambulances, while others have not. People who live nearby have said they are worried about the medical equipment in these cars and the qualifications of the drivers. Seeing medical teams responding in unmarked or non-standard vehicles has caused confusion and doubt about whether the care provided was safe and valid. Additionally, it indicates a reliance on private vehicles, suggesting issues with public emergency medical service systems, such as vehicle availability and staffing. Although these private vehicles assist with delivery, they show the urgent need for sustainable solutions to build the public healthcare system's infrastructure.

Making these kinds of rules would help make the care that private clinical cars offer more consistent and help people trust their services more. Private clinical cars are generally a good addition to public emergency medical services, especially when there are not enough resources to use regular ambulances. In Kazakhstan, they are becoming more popular because there are not enough cars and the need for medical transportation is growing. They are good for transfers between facilities and for non-emergency situations, but it's important to make strict rules and put money into public healthcare infrastructure to ease people's worries. Making the public ambulance fleet better and setting clear rules for private clinical vehicles will make patient transportation services more reliable and efficient as a whole.

2.2.3 Challenges during Transportation

Moving very sick patients, especially those with cardiovascular diseases (CVDs), is a hard and risky part of emergency medical care. Getting to higher-level treatment centers often requires transportation, but it can also cause a lot of clinical, logistical, and technical problems that could put patients' safety at risk if they aren't handled properly. A lot of planning, well-trained staff, the right medical equipment, and following standard procedures are all needed to make sure that the move from one point of care to another goes smoothly.

Clinical Risks

One of the biggest risks in the clinic is that the person's health will get worse while they are being moved. Patients who are very sick are naturally unstable and may have changes in their condition that could kill them while they are being moved. Common problems include low blood pressure, low oxygen levels, arrhythmia, respiratory failure, and cardiac arrest (Fanara et al., 2010). People with heart problems are even more at risk because their hearts are not working right. Even small changes in therapy or monitoring can cause sudden decompensation. According to (Droogh et al., 2015), up to 34% of critically ill patients have problems when they are moved between hospitals.

The most common problem is hemodynamic instability. Patients may also be exposed to environmental stressors like vibration, noise, and changes in temperature, especially when they are being transported by air or on the ground for a long time. These stressors can affect both patients and medical equipment, which makes it harder to keep an eye on them and treat them (Wiegersma et al., 2011). Also, some medical procedures, like mechanical ventilation or the use of vasopressors, are harder to do when you're moving, especially in small or crowded spaces.

Equipment and Technical Issues

Problems with technology and equipment are another big problem. Transport vehicles, such as ambulances, helicopters, and fixed-wing planes, must have life-support systems that include portable ventilators, defibrillators, infusion pumps, and monitoring equipment. However, devices can stop working or run out of battery, especially when they are moved around or used in extreme conditions (Dewhurst et al., 2001). Ensuring redundancy and battery backup is crucial, yet not always guaranteed, especially in resource-limited settings.

Compatibility between devices used in the originating and receiving facilities also poses a challenge. For example, a patient transferred to one type of ventilator may require reconfiguration or recalibration upon arrival, introducing delays in care. Furthermore, limitations in diagnostic capabilities during transport, such as the inability to perform laboratory tests or imaging, can prevent real-time decision-making.

Personnel and Training

The qualifications and experience of transport personnel are vital to patient safety. Transporting critically ill patients requires not only medical knowledge but also situational adaptability and familiarity with mobile critical care environments. Yet, in many systems, including those in Kazakhstan, shortages of trained critical care transport staff, especially in rural areas, can compromise transport quality (Messova et al., 2023). Inadequate staffing may lead to missed deterioration signs or delays in emergency interventions.

Communication breakdowns are another common issue. Another problem that happens a lot is that people cannot talk to each other. If the dispatch teams, hospitals, transport staff, and receiving facilities do not work together well, they could give out wrong information, cause delays, or not be ready enough when they get there. Good communication is necessary to share important patient information, expected arrival times, and specific treatment needs (Fanara et al., 2010).

Context in Kazakhstan

Kazakhstan's geography and infrastructure make logistical problems even worse. Long distances, bad roads, and bad weather like snowstorms and strong winds can all make transportation slower and put patients at even more risk (Kerimray et al., 2020). The Central Asian Medical Journal said that ambulances in remote areas often do not have the right equipment and may have to use old vehicles that cannot keep up with changing weather conditions or advanced life-support functions (Kobusingye et al., 2006). Kazakhstan has bought new ambulances, air medical services, and dispatch centers to modernize its emergency transportation system. Nonetheless, operational deficits remain, specifically to ensure that the standard of care is consistent across the regions. In summary, the continued transport of critically ill patients is probably the most complicated aspect of emergencies and critical care. Physiological deterioration, equipment malfunction, communication failure; all of that requires a comprehensive systems approach, involving suitably educated and trained human resources, calibrated and well-fitted equipment, and standard procedures. In the case of Kazakhstan and other contexts, we need to engage with infrastructure and workforce challenges to successfully improve the patient transport system and safety and outcomes for patients.

2.3 Decision making for transporting critically ill patients

2.3.1 Policy and Protocols in Kazakhstan

Kazakhstan has developed a detailed legal and regulatory system to cover all aspects of medical care, including the transfer of patients who are critically ill, especially those with cardiovascular diseases (CVDs). These protocols are aimed at guaranteeing patient safety, safe and consistent medical practices, and clearly defining the obligations of medical staff, including their actions during patient transfers.

Legal Framework and Regulatory Standards

The fundamental law of healthcare provision in Kazakhstan is the Code "On Public Health and the Healthcare System," which describes the general principles of the delivery of medical care, including emergency care and the transportation of patients.

In addition, the Ministry of Health has issued orders describing the standards for the orderly provision of anesthetic and resuscitation care. These orders consider the qualifications for medical staff, the equipment needed for the transportation of patients, and the necessity of transporting patients to another medical organization.

Protocols for Transporting Critically Ill Patients

The guidelines for transporting critically ill patients in Kazakhstan require thorough planning and coordination. Some of the key components include:

Assessment and Stabilization: Patients must be assessed and stabilized before transport. Stabilization should include assessment of vital signs, airway patency, and correction of any life-threatening conditions.

Qualified Medical Providers: Transfers should involve medical teams trained in the care of critically ill patients and emergency medical response. Anesthetic-resuscitator doctors are required during high-risk transports.

Transport Vehicle Equipment and Monitoring: Transports need to be conducted in vehicles equipped with potentially necessary medical devices, such as ventilators, defibrillators, and any monitoring devices that would be needed during transport. It is important to keep an eye on the patient's condition while they are being transported so that any problems can be found and dealt with right away.

Documentation and Communication: Detailed medical records should accompany the patient, and effective communication between the referring and receiving facilities is essential to ensure continuity of care.

The rules are strict, but it is difficult to follow them all over Kazakhstan, especially in rural and remote areas. Transport protocols can be harder to follow when there are not enough specialized medical staff, the infrastructure is not good, or there are problems with logistics. Kazakhstan has spent money to make its emergency medical services better, like by adding the ability to send air ambulances. These services are meant to make sure that people in remote areas get the medical care they need and that seriously ill patients get the right care at the right time.

In the end, Kazakhstan's rules and policies for moving very sick people show that they care about patient safety and making sure that medical practices are always the same. There are still problems with how things are being done, especially in places that do not have enough resources.

Ongoing investments in healthcare infrastructure and emergency services are important steps towards making sure that all patients get the critical care they need while they are being transported, no matter where they are.

2.3.2 Triage System

Efficient triage systems are very important when there are a lot of patients in emergency departments (EDs), especially when resources are limited and decisions need to be made quickly. The Emergency Severity Index (ESI) and other triage systems are used around the world to help doctors figure out which patients need the most urgent care based on how serious their condition is and how much care they need. The ESI system divides patients into five groups, from those who need immediate life-saving care to those who don't need much medical help at all (Nino et al., 2020).

Kazakhstan needs to use standardized triage systems like the ESI. According to Nurlan Baybazarov, the Minister of National Economy, about 40% of Kazakhstan's population, or about 7.6 million people, live in rural areas where access to advanced medical care is limited and emergency services often have trouble getting to people because of problems with logistics and infrastructure (Baybazarov, 2024). This demographic information shows how important it is to put care first, especially in an emergency when you are dealing with critically ill heart patients. Kazakhstan has already begun to change how emergency care is given. One of these changes is the use of a three-level color-coded triage model (Messova, et al., 2023). This is how the system works:

- Red Zone: Patients requiring immediate and intensive care (e.g., shock, cardiac arrest).
- Yellow Zone: Patients with serious conditions that are not immediately life-threatening.
- Green Zone: Patients with minor issues not requiring urgent intervention.

While this classification system reflects a foundational understanding of triage principles, it lacks the depth and predictive utility of multi-tiered tools like the ESI. Additionally, the quality and order of emergency care vary from hospital to hospital in Kazakhstan because each one has its own way of using triage protocols (Pivina et al., 2021).

Training, Infrastructure, and Challenges

One of the biggest problems that makes it hard to use uniform triage in Kazakhstan is that there are not enough trained staff. While structured emergency medicine education was initiated in 2018, and residency programs followed in 2019, there remains a significant gap in the availability of experienced emergency clinicians and nurses capable of executing accurate triage in high-pressure environments (Pivina et al., 2021). To make sure that the method is used the same way every time, it is important to have regular training sessions and certification programs that follow international best practices, like the ESI method. Infrastructure is another big issue in rural areas. Facilities often lack electronic health records, real-time monitoring systems, and connectivity for telemedicine consultations, factors that hinder timely triage, especially in mobile settings or during inter-facility transfers (Baybazarov, 2024). Moreover, the absence of protocol-backed support for certain transport modes, such as trains or private clinical vehicles, places additional pressure on emergency medical services (EMCRK, 2025).

Benefits of ESI and Future Directions

The Emergency Severity Index could offer several advantages to Kazakhstan's evolving healthcare framework:

- Improved patient flow: Stratifying patients reduces ED congestion and supports timely treatment.
- Resource optimization: Better allocation of critical resources like ICU beds and cardiology teams.
- Clinical standardization: Reduces variability in emergency decision-making across regions and facilities.
- Integration with digital tools: ESI can be incorporated into electronic triage platforms and hospital information systems.

International studies (Baumann & Strout, 2007; Tanabe et al., 2004) say that Kazakhstan should make a phased plan for ESI implementation. Testing should begin in major cities like Almaty and Astana and then gradually spread to regional hospitals, especially those that serve a lot of people in rural areas. Kazakhstan could greatly improve the speed, fairness, and quality of emergency care by using a standardized triage system like the ESI. Kazakhstan can improve the health of its patients, especially those who live in rural areas, by putting money into professional training, digital infrastructure, and regulatory support. This will make its emergency response plans more like those used around the world.

2.3.3 Alternative Scoring system APACHE II

The Acute Physiology and Chronic Health Evaluation II (APACHE II) scoring system is a common way to see how sick someone is in an intensive care unit (ICU). In 1985, Knaus et al. created

APACHE II. It gives a number that helps doctors decide how to care for patients and use resources (Knaus, 1985).

Globally, many different triage systems and acuity systems are being utilized within the emergency care system including the Emergency Severity Index (ESI), the Canadian Triage and Acuity Scale (CTAS) and the Manchester Triage System (MTS). Of these systems, ESI is by far the most commonly implemented in emergency departments. This is because it has very good granularity with its five-level classification of patients into their level of urgency and anticipated resource consumption. Therefore, when compared with Kazakhstan's triage system, which is only a three-color system, ESI has been associated with improvements in patient flow and resource allocation within high-volume emergency departments.

In this dissertation, we have chosen to use the APACHE II score as the primary measure of clinical severity. We chose the APACHE II score because it is a quantitative risk estimate based on physiological data and is designed specifically to assess the clinical severity of critically ill patients in the intensive care unit and patients who require intensive monitoring during their transport to an alternate facility. In addition to providing guidance on the triage priority and resource needs of a patient when they initially present to the emergency department, the APACHE II score provides a more direct representation of the patient's degree of physiological disruption and predicted mortality, both critical components in determining a patient's safety in inter-facility transport decisions.

However, it is important to highlight that these systems can work together instead of being seen as opposed to each other. Moving away from the current three color system and implementing a triage that looks like an ESI structure at the system level could enhance the way we initially allocate resources and the ability to transfer patients earlier between facilities. By using the Apache II systems in conjunction with the triage systems, we would be able to make better decisions regarding transferring high-risk patients using the correct method and at the correct time.

Components and Calculation

There are three main parts to the APACHE II score: the Acute Physiology Score (APS), age points, and chronic health points. The APS is based on 12 standard physiological tests that are done within the first 24 hours of being in the ICU. The Glasgow Coma Scale (GCS) score, body temperature, mean arterial pressure, heart rate, respiratory rate, oxygenation, arterial pH, serum sodium and potassium levels, creatinine, hematocrit, and white blood cell count are all examples of these (Knaus, 1985). A point value is given to each variable based on how much it differs from the normal range. If a patient is in a certain age group, they get age points. If they have a history of severe organ failure or are immunocompromised, they get chronic health points. The APACHE II score can be as low as 0 and as high as 71. A higher score means a more serious illness and a higher chance of death (Knaus, 1985).

Clinical Utility

There are a lot of things that APACHE II can do in a clinical setting. It helps doctors figure out how likely it is that a patient will die. This information is very important for deciding how much care a patient needs, what treatments are possible, and how to talk to their families about their prognosis (Knaus, 1985). APACHE II also helps with resource allocation by finding patients who might need more intensive monitoring and treatment, which is the best way to use ICU resources. It is also a useful tool for clinical research because it lets researcher's group patients by how severe their disease is and compare treatment outcomes more accurately between different groups of patients (Knaus, 1985).

Application in Kazakhstan

In Kazakhstan, using standardized scoring systems like APACHE II can make it easier to assess and treat patients who are very sick. Adding APACHE II to ICU protocols could help make clinical decisions and resource allocation more objective because the country is still working to improve its healthcare infrastructure and training. But some problems need to be fixed before it can be widely used. These include making sure that the right tools are on hand for taking physiological measurements, teaching healthcare workers how to correctly figure out and understand APACHE II scores, and changing the system to fit the local patient population and healthcare setting.

In conclusion, the APACHE II scoring system is useful in critical care medicine because it gives us a consistent way to figure out how bad a disease is and how a patient will do. It has some issues, but using it in real life, even in places like Kazakhstan, can help ICUs make better choices and give patients better care.

2.3.4 Trade-offs among Attributes: Maximizing Transportation Time Savings, Cost Savings, and Health Effects on Patient Transfers

When moving very sick patients, especially those with cardiovascular diseases (CVDs), making decisions often means weighing a number of goals that may be at odds with each other.

Healthcare providers, policymakers, and emergency coordinators need to keep three main things in mind: (1) getting the best health outcomes, (2) cutting down on transportation time, and (3) cutting down on the costs of transportation. Because they depend on the patient's health, the region's infrastructure, and the resources available, it is hard to weigh these trade-offs. This sub-chapter looks at these trade-offs from both a theoretical and an empirical point of view, with a focus on what they mean for Kazakhstan and other middle-income countries that are similar.

Maximizing Transportation Time Savings

Time is a critical factor in determining survival and recovery for patients suffering from acute cardiovascular events. The concept of the "golden hour" in medicine emphasizes that medical intervention within the first hour of symptoms, particularly for myocardial infarction or stroke significantly improves patient prognosis (Khandelwal et al., 2025). Therefore, rapid transport to a facility capable of delivering reperfusion therapy, cardiac catheterization, or surgical intervention is often prioritized above all else.

In countries like Kazakhstan, with vast geographical distances and uneven distribution of specialized medical centers, minimizing transportation time poses logistical challenges. According to the Ministry of National Economy, over 40% of the population resides in rural areas (Baybazarov, 2024). Ground transportation may take several hours due to underdeveloped infrastructure, especially in winter. In such cases, air transport (e.g., helicopters or fixed-wing aircraft) offers significant time savings, but it also introduces new challenges related to cost and safety.

Research shows that helicopter emergency medical services (HEMS) can reduce time-to-treatment in myocardial infarction cases by up to 40%, particularly when bypassing non-PCI-capable hospitals (Mørk et al., 2022). However, HEMS is often reserved for the most critical cases due to its operational cost and weather dependence.

Maximizing Transportation Cost Savings

While time savings can be lifesaving, they often come at high financial costs. Air ambulance operations can cost between $5,000 and $25,000 per trip, depending on equipment, distance, and medical staffing needs (Moore, 2025). In contrast, ground ambulances and even medical trains (used in some parts of Kazakhstan for outreach care) offer lower-cost alternatives but require longer travel times.

Cost-saving decisions are often justified when clinical urgency does not warrant immediate intervention. For example, patients with stable angina, post-acute myocardial infarction in recovery, or heart failure requiring planned interventions may be transported via ground-based services with fewer risks (Allen et al., 2020).

In low- and middle-income countries, public health systems often face budget constraints. In Kazakhstan, despite improvements in health financing, emergency care budgets remain limited, and decisions must consider the sustainability of services (Shurenova et al., 2024). The use of tiered transport systems reserving air or high-tech options for emergencies and using ambulances or trains for lower-risk transfers can lead to better cost-effectiveness at the population level.

Maximizing Health Effects

Ultimately, the overarching goal of medical transportation is to maximize health outcomes. This includes both short-term survival and long-term functional recovery. Transport decisions should ideally be based on evidence-based risk stratification tools such as the APACHE II or triage protocols that estimate the benefits of faster access to specialized care versus the risks of transport-related deterioration (Fanara et al., 2010; Knaus, 1985).

Clinical outcomes can be compromised if:

- The patient is transported too early without stabilization.
- The transport vehicle lacks adequate equipment for continuous monitoring.
- There is a mismatch between the patient's needs and the transport modality (e.g., using an unequipped private vehicle for a high-risk patient).

Studies indicate that 5–15% of critically ill patients experience adverse events during interfacility transport, including hypotension, hypoxia, and cardiac arrest (Kue et al., 2011b). Therefore, optimizing health outcomes also includes minimizing risks during transit, not just delivering patients quickly.

Balancing the Three Attributes: A Multiattribute Trade-off

The trade-offs among time, cost, and health outcomes are central to the framework of multiattribute decision analysis. In these kinds of frameworks, in an emergency that could kill someone, decision makers might give transport time savings and health outcomes more value, but cost a lot less. Conversely, when patients are stable or resources are limited, though, cost-effectiveness may come first.

The National Coordination Centre for Emergency Medicine (NCCEM) in Kazakhstan often has to make these kinds of choices. When NCCEM has to choose between an air ambulance, a ground ambulance, or a clinical vehicle, they have to think about more than just the patient's clinical profile. They also need to think about the weather, whether the vehicles are available in the area, and how much it will cost to use them. For instance, NCCEM cannot drive people in private cars because there are not any medical staff or set procedures (EMCRK, 2025).

In short, the decision to move critically ill cardiovascular patients means balancing three conflicting goals: saving time, lowering costs, and improving clinical outcomes. You have to choose between these things in emergency medicine. Structured decision frameworks, good clinical protocols, and a tiered resource allocation model can help you get the best results in all three areas. Kazakhstan needs to find this balance by making its health information systems better, making its transportation rules clearer, and training its staff in multiattribute decision analysis.

Chapter 3 Methodology

Getting critically ill patients with heart disease to their appointments safely and on time is a tough decision-making problem, especially in countries with big areas and specialized healthcare facilities that are not always easy to find. Kazakhstan's advanced cardiac centers are hard to get to because of the patients' serious health problems, which makes it even harder to find a balance between cost, time, and medical safety. When making decisions with such high stakes, you need a strong analytical framework that can handle many, often conflicting, goals and outcomes that are not always clear.

This research uses Multiattribute Utility Theory (MAUT) as its main method to deal with this complex problem. MAUT offers an organized and methodical approach to modelling decision-making under uncertainty using multiple criteria and is particularly suited to healthcare applications where tradeoffs among cost efficiency, clinical or health outcomes, and operational constraints are common.

In this chapter, the overall research design and methodological strategy that was used in the study are discussed. The methodology is structured around three analytical approaches that provide their own unique view and level of complexity:

1. **Multiattribute analysis under Partial Utility Independence (PUI) condition**: This is the underlying method that is used in the study, which will allow for the modeling of interdependencies among decision attributes, capturing the subtle and realistic preferences of decision makers encountering a medical emergency. The PUI framework provides flexibility in utility modeling and a more realistic representation of stakeholder values and trade-offs (Abbas, 2010; Abdildin, 2014; Abdildin & Abbas, 2016).

2. **Multiattribute analysis under Utility Independence (UI) assumption** (R. Keeney & Raiffa, 1976): The UI model, as a comparative approach, assumes that each attribute is utility independent of the other attributes. This assumption allows the construction of the utility function to be simplified to the multilinear form. Although it is less flexible to construct utility functions, the multilinear form is used widely in literature, and it is simpler, computationally more efficient, and easier to interpret.
3. **The Single Attribute Evaluation Method:** This method rates each option based on only one attribute like cost, time, or patient safety. This method is not as advanced as multiattribute methods and does not consider trade-offs, but it is a good place to start. It is often used in business to make quick choices when there is not a lot of time or information. Adding this method shows how helpful multiattribute analysis can be in medical logistics that are difficult to analyze.

This chapter goes into detail about each of these methods, explaining why they were chosen, what data is needed, and how to build the utility functions step by step. Methodological triangulation makes sure that the research results are not only correct from an analytical point of view, but also useful in real-life emergency healthcare situations and relevant to the situation.

In short, this chapter sets the stage for a full decision analysis framework that is specific to moving heart patients who are in serious condition. The study's goal is to help people make informed, open, and fair decisions about how to best use medical transportation resources by looking at things from different points of view using the MAUT framework.

3.1 Multiattribute Utility Function under Partial utility independence condition

When making complicated healthcare decisions, like figuring out the best way to get critically ill cardiovascular patients to their appointments, the things that matter are almost never separate in terms of utility. The time it takes to get to a specialized clinic may affect how safe patients are while they are being transported, which may be related to the cost of getting there. In these cases, assuming full utility independence can make models too simple and not show what decision makers really want. This study uses a multiattribute decision-making method based on Partial Utility Independence (PUI) to deal with this.

Partial Utility Independence is a formal way to relax the strict utility independence condition that is often used in traditional multiattribute utility theory (Abdildin & Abbas, 2013). PUI says that when it comes to overall utility, one or more attributes may depend on each other. However, it is still possible to claim conditional independence in a structured way. In healthcare, this framework is very helpful because it is not always easy to see the trade-offs between cost, time, and clinical outcomes.

Rationale for Using PUI

There are both theoretical and practical reasons for using the PUI framework in this study.

Realism in Choices: People who make decisions about medical logistics often look at more than one factor at a time, and their preferences show how different factors affect each other. For example, a way of getting around that saves time might not be as useful if it puts patients' safety at risk, or the other way around. PUI captures this interdependence more faithfully than additive models.

Modelling with flexibility: The PUI-based model does not need all the independence assumptions. Conditional utility assessments are easier to use because they let decision makers make realistic judgements.

In the literature, earlier studies (Abbas, 2018; Abdildin & Abbas, 2016) have shown that PUI models are based on solid theory and can help with decision-making in real-world industries. Utility trees, basic expansion theorems, and conditional utility functions are all good ways to model hard problems with more than one attribute, according to these studies (Abdildin, 2014).

Conceptual Framework

We can use the Basic Expansion Theorem (Abbas, 2010) to create the multiattribute utility function based on the PUI assumption. This theorem says that you can write the total utility $U(X_1, X_2, X_3)$ as a sum of conditional and marginal utility functions. A utility tree or influence diagram is often used to show how the attributes are related to each other (Abdildin, 2014).

The basic expansion theorem and the utility dependence matrix could be used to break down the utility function under PUI into three parts: X_1 for savings on transportation costs, X_2 for savings on time, and X_3 for safety during transportation.

This formulation reflects the conditional dependencies among the attributes. Each term is a utility function assessed under specific conditions (e.g., assuming a particular attribute is fixed at its best or base level). The assessments involve determining indifference probabilities using structured lotteries, ensuring that the DM's risk preferences and trade-offs are accurately represented.

Methodological Implementation

To apply the PUI approach in practice, the following steps are taken:

1. Attribute and Alternative Identification: Define the attributes and transportation alternatives relevant to the decision problem (as described in sections 2.2 and 2.3).
2. Assessment of Partial Independence: Use pairwise comparisons and scenario-based questionnaires to determine which attributes can be considered conditionally independent of others.
3. Construction of Utility Dependence Matrix (UDM): Summarize the interdependencies among attributes and organize them into a matrix form to guide the decomposition of the utility function.
4. Conditional Utility Elicitation: Conduct interviews with the decision maker to assess conditional utility values. These values are typically obtained through standard gambling questions and recorded as indifference probabilities.
5. MUF Construction and Normalization: Assemble the multiattribute utility function using the BET framework and normalize it to a [0, 1] scale for comparability across alternatives.
6. Integrating with Decision Tree: Use the MUF you got to find out what the expected utilities are for each of the situations shown in a decision tree. We give each attribute possible outcomes like low, base, and high values, to help us figure out what the expected utilities are.

3.1.1 Utility Dependence Matrix (UDM) (Abbas, 2010)

It is very important to know how the attributes depend on each other when you construct a multiattribute utility function (MUF). The Utility Dependence Matrix (UDM) (Abbas, 2010) is a structured, visual, and mathematical tool for representing these interdependencies. Utility theory describes the UDM as an $n \times n$ incidence matrix. Each cell tells you if there is utility independence (UI) or dependence between two attributes of the decision problem (Abbas, 2010).

Utility independence (UI) means that a decision maker's preference for uncertain outcomes involving one attribute stays the same, no matter what the fixed levels of another attribute are (R. Keeney & Raiffa, 1976). When there is UI between attributes, the MUF can often be constructed much simpler. This means that fewer assessments of utility are needed (Abbas, 2018). The UDM lets you keep track of and formalize these more complicated dependencies, though, if UI is not fully present and attributes show partial utility independence (PUI). UI is present if a cell in the UDM is blank. If there is a circle inside a cell, it means that UI is not present between the attributes (Abdildin & Abbas, 2013).

A UDM is especially useful for determining whether a decision problem can be modelled with a multiattribute utility function (Abbas, 2010). This is a specific kind of MUF that uses PUI to make evaluations easier without assuming full independence. A UDM is considered to be in canonical form if only zero or one row contains dependency assertions, or if all dependency assertions are symmetric and restricted to a subset of attributes (Abbas, 2010; Abdildin & Abbas, 2013). In practice, canonical forms are very helpful because they make math easier and let you break the utility function into smaller parts. According to (Abdildin & Abbas, 2016), studies of the uranium mining industry showed that canonical forms could be used in real life. UDMs have been used successfully in complicated industrial and policy settings to help with modelling preferences when there is uncertainty.

In a study of the deep borehole filter restoration problem (Abdildin & Abbas, 2016), a UDM was used to look at the decision maker's preference structure over a number of attributes, such as safety, profit, and protecting the environment. The matrix showed that the experts' preferences imply PUI. This observation emphasizes the value of utilizing UDMs not only to model but also to validate the decision framework before applying quantitative evaluations.

In summary, the Utility Dependence Matrix is an essential tool for multiattribute decision analysts. It provides a structure for formalizing assumptions about interdependence, selecting the appropriate functional forms for utility modeling, and producing decisions that more accurately reflect the parameters of stakeholder preferences under conditions of uncertainty. As demonstrated through applications as diverse as energy policy and healthcare transport, the UDM will significantly enhance both the rigor and transparency of the decision process.

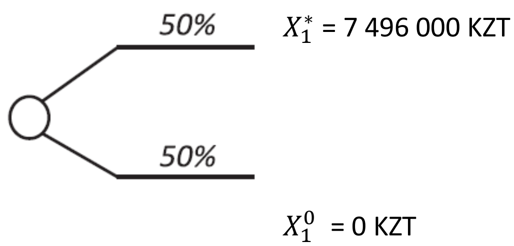
As an example, to construct UDM following Questions were asked to DM:

Question 1. Dependence of Savings Costs on Transportation (X_1) on the Impact of Transportation on Health (X_3)

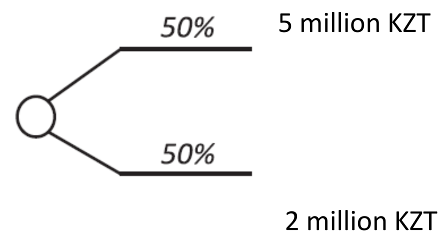
a) There are two cases, A and B, and in each case, there are two options for the cost of transporting the patient, which can occur with equal probability (50/50). Which case would you prefer in Scenario 1?

Scenario 1: In both cases, X_3^* = 25 (impact of transportation on health)

A:



B:



Choose one of the three options:	*Case A*	Indifferent (A and B are the same)	*Case B*

Other questions are represented in Appendix 6. After completing Appendix 6, UDM could be constructed.

3.2 Multiattribute Analysis under Utility Independence Assumption (UI)

As a comparative and complementary method, utility independence (UI) offers an alternate framework for multiattribute decision analysis that greatly reduces the complexity in the construction and assessment of the utility function. The starting point for UI is that each attribute is utility independent from others; this means the decision maker's preferences over uncertain outcomes of one attribute do not depend on the fixed values of the other attributes. This process will permit decision makers to use functional forms that are structured and very well-established, especially the multilinear model that is often found in decision science literature due to its simplicity and analytical feasibility (Abbas, 2018; R. Keeney & Raiffa, 1976).

Rationale for Using the UI Model

The utility independence assumption presents several practical advantages for conducting a decision model, especially when the objective is to conduct a computationally efficient but rigorous comparative assessment.

Ease of utility construction: In the case where there is a UI condition, the overall utility function can be defined as a sum of simple multi-attribute utility function and their interaction terms. This means that the felicitating requires considerably less time and reduces the number of conditional assessments needed.

Clear Analytical Framework: The multilinear framework is more transparent and easier to interpret, and the less difficult to conduct a sensitivity analysis. Decision makers and stakeholders can easily appreciate the contribution each attribute makes to overall utility, and understand the trade-offs made across attributes.

Comparative Value: While the UI model may not be able to explain all the nuances of preference interdependence, it is useful as a benchmark. It allows researchers to compare across the more flexible PUI model to a constrained but analytically neat model.

Theoretical Basis: The UI model has strong theoretical grounding and has been validated in multiple applied contexts, including healthcare operations, environmental policy, and strategic planning contexts with multiple stakeholders. Including the UI model in this study is consistent with the best practices in decision analysis, as this supports a comparison and assessment of method robustness.

Conceptual Framework

The multilinear form of the multiattribute utility function (R. Keeney & Raiffa, 1976) can be used when all attributes are thought to be UI of their complements. For three attributes X_1, X_2, and X_3, the utility function $U(x_1, x_2, x_3)$ can be expressed as

$$U(x_1, x_2, x_3) = \sum_{i=1}^{3} k_i \, U_i(x_i) + \sum_{i<j} k_{ij} U_i(x_i) U_j(x_j) + k_{123} U_1(x_1) U_2(x_2) U_3(x_3)$$

Here:

$U_i(x_i)$ is the single-attribute utility function for attribute i;

k_i, k_{ij}, and k_{123} are scaling constants representing the relative importance and interaction effects among the attributes.

The coefficients are typically determined through structured preference elicitation from the decision maker using methods such as the standard gambling or lottery equivalence approach. These methods involve comparing hypothetical outcomes to establish the decision maker's risk attitude and relative valuations.

Methodological Implementation

The implementation of the UI model involves several key steps:

1. Single-Attribute Utility Assessment: Each attribute's utility function $U_i(x_i)$ is assessed independently, typically using a three-point elicitation method (low, base, high outcomes). The indifference values are used to construct a normalized utility curve for each attribute.
2. Scaling Constant Elicitation: The interaction terms and weights k_i, k_{ij}, and k_{123} are assessed through pairwise comparisons and combination lotteries, ensuring that the overall utility function reflects the decision maker's trade-off preferences under the assumption of independence.
3. Utility Function Construction: The full multilinear utility function is constructed using the elicited utility values and constants. This function is then used to compute the utility of each alternative in the decision space.

4. Application in Decision Tree Analysis: The utility values derived from the multilinear MUF are integrated into the decision tree model developed earlier. Expected utilities are calculated based on the probabilities assigned to each scenario.

After completion of the questionnaire in appendix 7, all coefficients k_1, k_2, k_3, will be determined. Other coefficients could be calculated such as k_{12}, k_{13}, k_{23}, k_{123}.

3.3 Single Attribute Evaluation Method

The Single Attribute Evaluation Method makes it easy to choose by looking at each choice one at a time and seeing how well it meets one requirement. This means looking at each transportation option one at a time for critically ill cardiovascular patients based on the following factors:

- X_1: Transportation cost savings
- X_2: Time savings
- X_3: Patient safety (measured using APACHE II scores)

This method ignores any interaction or trade-offs among these attributes, treating them as isolated dimensions of value. This method is easy to use, which makes it harder to capture the complexity of real-world preferences, but it works better in some situations.

This method should be part of research design for a few important reasons. For one, it gives a clear and simple baseline that can be used to compare more complicated multiattribute methods. When you see how decisions change when only one thing is taken into account, you can see how important trade-off modelling is for making full decisions. In real life, people who make decisions in emergency medical settings often do not have enough time or access to all the information they need. When this happens, people use heuristics or simple scoring systems to make choices. These systems often put more weight on one factor, like time or patient safety, than on others. This method can help you figure out which options are best for each attribute. For example, if one way of getting around is always safer than others, this information could help people decide what to do or make them want to learn more, even if that way is not the best in a full multiattribute analysis. When talking to stakeholders who only care about one goal, like keeping costs down or lowering clinical risk, it can be helpful to show them results from a single attribute method. It helps you understand things in pieces before putting them all together.

Conceptual Framework

This method gives each transport option a score based on how much of one attribute it has. For each attribute, the alternatives are ordered from most to least desirable, based on their observed or estimated performance. For example:

For X_1 (cost savings): the alternative with the highest cost reduction is ranked highest.

For X_2 (time savings): the alternative with the shortest transportation duration is ranked highest.

For X_3 (patient safety): the alternative with the lowest adverse change in APACHE II score is preferred.

These attribute-specific rankings provide three different perspectives on the set of alternatives. No composite utility function is constructed, and no preference information about trade-offs is required or incorporated.

Role in Research

In this study, the single attribute evaluation method is employed for comparative and illustrative purposes. While it is not used to make the final recommendation, it establishes a baseline for evaluating how much additional insight and accuracy is gained by applying multiattribute models. It also serves as a practical reference for cases where only limited data are available or when a fast, attribute-specific decision is required in the field.

This chapter has outlined the methodological framework adopted for analyzing the transportation alternatives available for critically ill cardiovascular patients in Kazakhstan. Faced with the urgent, life-sensitive nature of such decisions, this research necessitates a robust, multi-criteria decision-making approach that not only captures the complexity of the problem but also aligns with the preferences of key stakeholders in emergency medical care.

At the core of the methodology is the application of Multiattribute Utility Theory (MAUT), a proven decision analysis technique well-suited to handling problems involving multiple conflicting objectives and inherent uncertainties. The principal method employed in this study multiattribute utility analysis under the Partial Utility Independence (PUI) condition was selected for its capacity to reflect realistic decision-maker preferences where attributes such as cost, time, and patient safety interact in non-trivial ways. The framework was implemented using structured utility elicitation methods, supported by decision trees and the Basic Expansion Theorem, with dependencies captured via the Utility Dependence Matrix (UDM).

To ensure methodological rigor and provide a reference point, a comparative analysis under the Utility Independence (UI) assumption was also developed. This model offers a simplified and widely recognized formulation using a multilinear additive utility function. Although less flexible, the UI-based approach remains valuable for benchmarking and sensitivity testing.

Additionally, a Single Attribute Evaluation Method was employed to illustrate how decisions might be made in the absence of trade-off analysis. While simplistic, this method reflects real-world practices in time-constrained environments and helps clarify the unique contributions of full multiattribute models.

By applying this triangulated methodological approach, the study is well-positioned to generate decision-support insights that are not only theoretically grounded but also practically applicable. The next chapter will apply these methods to real data, assess utility functions for each alternative, and derive rankings based on the decision-maker's preferences. This analysis will ultimately guide evidence-based recommendations for improving emergency transportation logistics in the Kazakhstani healthcare system.

Chapter 4 Results

In this chapter, we show all results: primary data from NCCEM, National Railway Company, and experts' assumptions. The chapter will be divided into three sub-chapters: single criteria assessment, multilinear form, and Multiattribute Utility Function under Partial Utility condition.

The main objective of addressing the issue of transporting critically ill patients, as seen from the perspective of the head doctor, is to efficiently and cost-effectively transfer these patients while maximizing transportation safety. The availability of alternative modes of transportation is also a crucial aspect in decision analysis. Therefore, the overall goal encompasses the following objectives:

• Maximize transportation cost saving

• Maximize saving time on transportation

• Maximize safety during patient transportation.

Table 2: Attributes to the decision problem on transporting critically ill patients

Attribute	Measure	Range	
		Best	**Worst**
X_1 – cost saving	Tenge	7 496 000	0
X_2 – saving time	minutes	3254	0
X_3 – patients' safety	APACHE II	25	0

4.1 Single criteria

Each of the five options has benefits and drawbacks. Given three attributes, there are three ways all options could be rated. Their costs, speed, and impact on the patient allow us to rate them. Following tables 2, table 5 and table 6 illustrate max, high-base-low, and min values for each alternative. In table 2, Transportation cost saving (X_1) is the difference between the maximum cost for transportation (an airplane) and the cost of other modes of transportation. For instance, if we use trains, we may save 7 496 000 tenge compared to airplanes. This feature pertains to the costs incurred in transporting critically ill patients. Thanks to the availability of free healthcare in Kazakhstan, the expenses incurred by patients are constantly monitored and the NCCEM provides documentation for every treatment rendered. We should note that the cost of transporting patients does not include the salary of medical personnel, i.e. it includes only the transportation cost. We use the local currency, Tenge, which had an approximate exchange rate of 1 USD = 450 Tenge during calculations.

Table 3: X_1 attribute values, KZT (tenge)

	Max	**High**	**Base**	**Low**	**Min**
Airplane	3,500,000	3,000,000	1,500,000	500,000	0
Helicopter	4,000,000	3,500,000	1,700,000	1,000,000	500,000
Train	7,496,000	7,495,000	7,490,000	7,472,000	7,470,000
Ambulance	7,492,000	7,491,000	7,485,000	7,478,000	7,477,000
Clinical cars	7,472,000	7,470,000	7,460,000	7,440,000	7,430,000

Saving time on transportation (X_2) is the difference between maximum duration for transporting critically ill patients (e.g. train) and the time by other modes of transport. We have analyzed 88 routes (from 44 cities to Astana and from 44 cities to Almaty, see map in Fig. 1). All data has been developed from several sources (Table 3). Some cities do not have airports, and to calculate delivery time via plane to Astana and Almaty, we have added transportation time by ambulance/car to the airports of the nearest cities. We also calculated round trips for both airplane and helicopter modes.

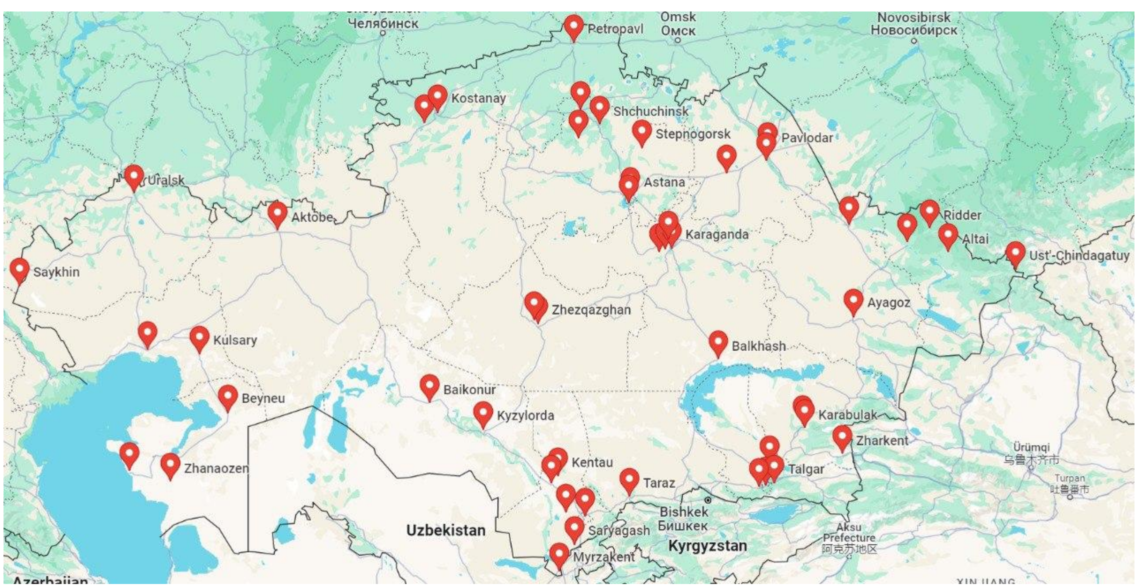


Figure 3: Map of the Republic of Kazakhstan (adapted from yandex.com)

Table 4: Sources used to estimate transport time

Helicopter	https://www.sennair.at/en/flugrechner
Ambulance / Clinical Car	https://www.google.com/maps
Airplane	https://www.google.com/maps
Train	https://bilet.railways.kz/

Table 5: Transportation time From A to B (min)

	From	To	Helicopter	Car	Airplane	Train
1	Almaty	Astana	546	963	140	905
2	Shymkent	Astana	558	1111	180	1128
3	Aqtöbe	Astana	566	1270	190	1500
4	Qaraghandy	Astana	108	167	510	182
5	Taraz	Astana	516	983	200	879
6	Öskemen	Astana	450	657	150	1082
7	Pavlodar	Astana	226	281	540	372
8	Atyraū	Astana	716	1740	260	2280
9	Semey	Astana	352	511	160	757
10	Qyzylorda	Astana	466	866	170	1860
11	Aqtaū	Astana	972	2160	250	2700
12	Qostanay	Astana	324	553	120	662
13	Oral	Astana	784	1376	250	2460
14	Türkistan	Astana	510	1742	200	1680
15	Petropavl	Astana	246	352	140	400
16	Kökshetaū	Astana	132	206	720	220
17	Temirtaū	Astana	92	145	510	315
18	Taldyqorghan	Astana	482	1044	140	1103
19	Ekibastuz	Astana	154	212	844	372
20	Rudnyy	Astana	338	601	222	608
21	Zhezqazghan	Astana	258	541	110	880
22	Qaskeleng	Astana	544	941	278	960
23	Baikonur	Astana	482	1620	542	2100
24	Zhangaözen	Astana	924	2160	656	2820
25	Kentaū	Astana	494	1070	306	1740
26	Balqash	Astana	306	452	1110	711
27	Sätbayev	Astana	258	523	170	903
28	Kulsary	Astana	758	1680	640	3206
29	Talghar	Astana	550	803	320	945
30	Saryaghash	Astana	614	1023	390	2784
31	Konaev	Astana	514	930	272	1095
32	Zharkent	Astana	566	1068	560	1110
33	Arys	Astana	558	1165	254	1740
34	Aqsū	Astana	220	271	604	664
35	Ridder	Astana	480	753	298	1500
36	Zyryanovsk	Astana	518	813	510	1226
37	Qarabulaq	Astana	544	1088	286	1188
38	Soran	Astana	102	182	560	216
39	Beyneū	Astana	646	1860	892	2280
40	Ayagöz	Astana	416	769	656	1279
41	Ust'-Chindagatuy	Astana	634	1026	866	1500
42	Saykhin	Astana	998	2340	1460	2880
43	Myrzakent	Astana	668	1345	656	1366
44	Isakovka	Astana	274	429	328	494

45	Astana	Almaty	554	959	200	921
46	Shymkent	Almaty	340	497	130	749
47	Aqtöbe	Almaty	954	1692	300	1980
48	Qaraghandy	Almaty	442	783	170	798
49	Taraz	Almaty	250	346	120	422
50	Öskemen	Almaty	488	848	200	1590
51	Pavlodar	Almaty	566	1081	210	1600
52	Atyraū	Almaty	1122	2142	340	2470
53	Semey	Almaty	472	878	190	1200
54	Qyzylorda	Almaty	522	781	190	1140
55	Aqtaū	Almaty	1162	2607	360	3256
56	Qostanay	Almaty	832	1463	270	2379
57	Oral	Almaty	1186	2106	340	2470
58	Türkistan	Almaty	386	581	160	860
59	Petropavl	Almaty	792	1230	230	1359
60	Kökshetaū	Almaty	710	1100	508	1179
61	Temirtaū	Almaty	438	811	280	845
62	Taldyqorghan	Almaty	130	196	130	390
63	Ekibastuz	Almaty	534	999	330	1278
64	Rudnyy	Almaty	716	1560	390	2439
65	Zhezqazghan	Almaty	492	1078	160	1140
66	Baikonur	Almaty	624	982	542	1307
67	Zhangaözen	Almaty	1092	2640	520	3346
68	Kentaū	Almaty	380	576	244	902
69	Balqash	Almaty	240	531	770	975
70	Sätbayev	Almaty	502	1089	176	1153
71	Kulsary	Almaty	1032	2100	700	2050
72	Saryaghash	Almaty	372	606	322	876
73	Koschi	Almaty	538	936	236	986
74	Arys	Almaty	372	548	534	1091
75	Aqsū	Almaty	550	1055	302	1554
76	Stepnogorsk	Almaty	608	1035	362	1066
77	Shchūchīnsk	Almaty	668	1049	398	1071
78	Ridder	Almaty	528	969	452	1716
79	Zyryanovsk	Almaty	516	962	520	1730
80	Qarabulaq	Almaty	328	477	230	789
81	Soran	Almaty	446	774	232	850
82	Beyneū	Almaty	978	2280	1232	2814
83	Ayagöz	Almaty	334	578	586	805
84	Shakhtīnsk	Almaty	446	802	268	845
85	Ust'-Chindagatuy,	Almaty	576	1168	1034	2007
86	Saykhin	Almaty	1342	2400	1540	3070
87	Myrzakent	Almaty	420	738	600	990
88	Isakovka	Almaty	700	1312	420	1454

Table 6: X_2 attribute values, minutes

	Max	High	Base	Low	Min
Airplane	3236	3189	3042	2611	1806
Helicopter	3254	3101.8	2830	2386.6	2004
Train	3164	2873.6	2206	807	0
Ambulance	3201	2995.8	2383.5	1244.2	706
Clinical cars	3201	2995.8	2383.5	1244.2	706

Transport safety of patients' health (X_3) is the difference between the maximum score of APACHE II that has risen during the transportation of the patient and other scores that may rise when we transport via other modes of transportation.

The APACHE II (Acute Physiology and Chronic Health Evaluation II) scoring system is a widely utilized method for assessing the severity and prognosis of critically ill patients admitted to intensive care units (ICUs). Developed by Knaus et al in 1985, the APACHE II model incorporates a combination of twelve physiological variables, the patient's age, and previous health status to compute a score that correlates with the risk of hospital mortality. This score helps in identifying patients who are at higher risk of mortality, thereby aiding clinicians in making informed decisions regarding the level of care and resource allocation. Moreover, APACHE II is valuable for clinical research and benchmarking ICU performances.

Table 7: X_3 attribute values, (APACHE II score)

	Max	High	Base	Low	Min
Airplane	25	22	20	17	15
Helicopter	23	22	21	18	15
Train	22	21	17	15	10
Ambulance	21	20	15	10	5
Clinical cars	20	18	10	4	0

The data in Tables 2,5 and 6 do not definitively indicate the superior method. Should a decision maker in the field prioritize the methods based on cost, time, or the likelihood of successful transportation separately, they might rank them as depicted in Table 7. This ranking reveal that no single option consistently outperforms the others. For instance, the train is the cheapest mode of transportation, but it is also the slowest. Thus, a systematic approach is necessary to determine the optimal choice.

Table 8: Ranking of the modes on cost reduction, time saving, and transportation safety

Modes of transportation	Rank		
	Cheapest	**Fastest**	**Less harmful**
Airplane	#5	#4	#1
Helicopter	#4	#3	#2
Train	#1	#5	#3
Ambulance	#2	#1	#4
Clinical cars	#3	#1	#5

Ultimately, no one choice can rule across all criteria since every form of transportation shows different advantages and disadvantages when assessed separately for cost, speed, or patient impact.

Though the rail is inexpensive, it is much slower; the airline shows quicker travel, but its prices could be excessive. Single-criterion evaluation hence produces no obvious, universally better approach. Thus, to find the best balance among cost, time, and successful patient outcomes, one must use a methodical, multiattribute decision-making process.

4.2 Multilinear form

What happens if we do not assess the DM's preferences and simply assume utility independence among the attributes? If every attribute is UI of its complement, the MAU function can be expressed in the form of a multilinear equation (R. Keeney & Raiffa, 1976):

$$\begin{aligned} U(x_1, x_2, x_3) = {} & k_1 U_1(x_1) + k_2 U_2(x_2) + k_3 U_3(x_3) \\ & + k_{12} U_1(x_1) U_2(x_2) + k_{13} U_1(x_1) U_3(x_3) \\ & + k_{23} U_2(x_2) U_3(x_3) + k_{123} U_1(x_1) U_2(x_2) U_3(x_3) \end{aligned} \quad (12)$$

where,

$$k_1 = U(x_1^*, x_2^0, x_3^0) = 0.25 \quad (13)$$

$$k_2 = U(x_1^0, x_2^*, x_3^0) = 0.20 \quad (14)$$

$$k_3 = U(x_1^0, x_2^0, x_3^*) = 0.65 \quad (15)$$

$$k_{12} = U(x_1^*, x_2^*, x_3^0) - k_1 - k_2 = 0.30 - 0.25 - 0.20 = -0.15 \quad (16)$$

$$k_{13} = U(x_1^*, x_2^0, x_3^*) - k_1 - k_3 = 0.80 - 0.25 - 0.65 = -0.10 \quad (17)$$

$$k_{23} = U(x_1^0, x_2^*, x_3^*) - k_2 - k_3 = 0.70 - 0.20 - 0.65 = -0.15 \quad (18)$$

$$\begin{aligned} k_{123} &= 1 - k_1 - k_2 - k_3 - k_{12} - k_{13} - k_{23} \\ &= 1 - 0.25 - 0.20 - 0.65 - (-0.15) - (-0.10) \\ &\quad - (-0.15) = 0.30 \end{aligned} \quad (19)$$

The scaling constants were assessed from the expert using questions as shown below for k_3 :

What probability p *makes you indifferent between: (i) receiving* (x_1^0, x_2^0, x_3^*) *for sure and (ii) gambling between* (x_1^*, x_2^*, x_3^*) *with* p *and* (x_1^0, x_2^0, x_3^0) *with* $(1-p)$ *?*

In this example, the expert's answer was $p = 65\% \Rightarrow k_3 = U(x_1^0, x_2^0, x_3^*) = 0.65$

Using this multilinear form, we have results presented in Table 8.

Table 9: The order of alternatives under utility independence condition

Rank order	Alternatives	E-value of U-value
#1	Train	0.671
#2	Helicopter	0.614
#3	Ambulance	0.602
#4	Airplane	0.585
#5	Clinical cars	0.477

4.3 Multiattribute Utility Function under Partial utility independence condition

4.3.1 Decision tree

The decision tree represents a decision node (rectangle) at which the DM considers five alternative transportation modes to use for the patient transportation, and the chance nodes (circles), where the outcomes of each attribute may take high, base, or low values with certain probabilities (0.25, 0.5, and 0.25, respectively). There are 135 (namely, 5*3^3) outcomes in this decision tree (Fig. 2). The overall goal is to find the best alternative by comparing their expected utility values, which should be calculated. Hence, first, we assess the statistical values (i.e. high, base, low) of each attribute for all alternatives. Secondly, we need to assess utility interdependence amid the three following attributes, i.e., we should capture the DM's preferences in terms of these three attributes using a questionnaire. Thirdly, based on interdependencies, we should determine the functional form of MAU function, $U(X_1,X_2,X_3)$. Next, we need to assess the MAU function (another questionnaire) and calculate the expected utility for each alternative. Finally, choose the alternative with the highest expected utility value.

4.3.2 Utility Dependence Matrix **(Abbas, 2010)**

Utility dependence and utility independence (UI) conditions among attributes can be represented in the form of the utility dependence matrix (UDM), an $n \times n$ incidence matrix with non-vacant cells in the main diagonal. According to Abbas, a vacant cell in row i and column j of UDM asserts the utility independence (UI) relation of X_i from X_j. The UDM for the multilinear form of the MUF is represented by an identity matrix, as shown in Fig. 3 (a). Thus, all three attributes are utility independent from their complements. UDM in Fig. 3 (b) has been constructed through assessing DM's preferences via a formal test adapted from (appendix B). The matrix shows that attribute X_1 is UI from its complement, and X_3 UI X_2. The concept of UDM was explained in more detail by (Abbas, 2018). UDM of a decision problem can be created by assessing the DM's preferences using a questionnaire and influences the functional form of MAU function.

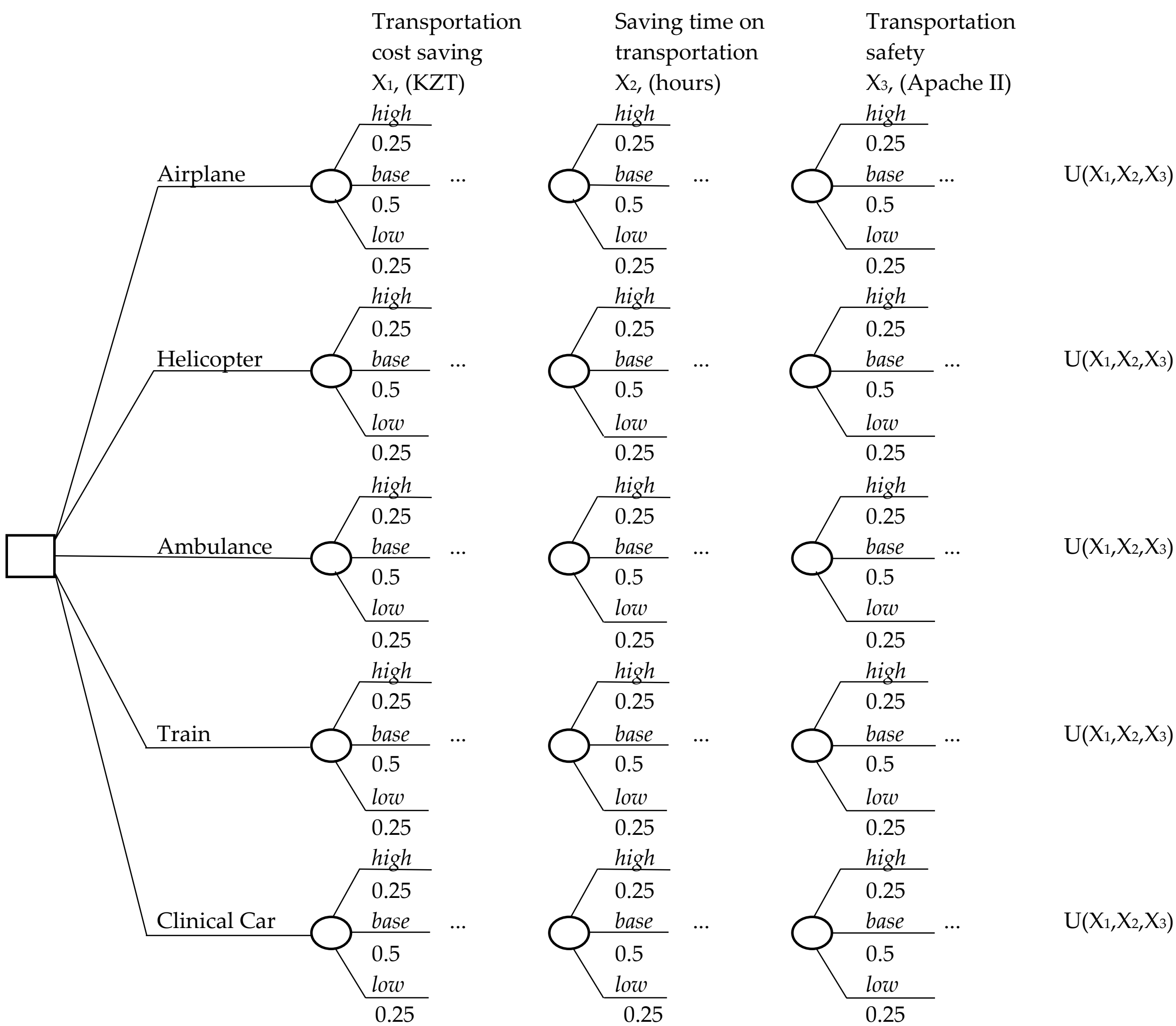


Figure 4: Partial decision tree constructed for transporting critically ill patients with CVD

The medical expert was instructed about the questions in the questionnaires. The expert did not have much difficulty in answering questions. The whole assessment took around eight hours with two lengthy breaks. First, the UDM matrix was assessed, and then, the terms of the MUF.

	X_1	X_2	X_3
X_1	○		
X_2		○	
X_3			○

(a)

	X_1	X_2	X_3
X_1	○		
X_2	○	○	○
X_3	○		○

(b)

Figure 5: (a) UDM represents mutual utility independence; (b) UDM assessed from the expert

UDM in Fig. 3b allows the simplification of conditional functions(Abbas, 2018) as follows:

$$X_1\ UI\ \overline{X_1} => U(x_1|x_2,x_3) = U(x_1|x_2^0,x_3^0) = U(x_1|x_2^*,x_3^*), \quad (1)$$

$$X_3\ UI\ X_2 => U(x_3|x_1,x_2) = U(x_3|x_1,x_2^0) = U(x_3|x_1,x_2^*), \quad (2)$$

where $\overline{X_1}$ implies complement of X_1, while 0 and * in superscripts repesent the worst and best values of the attributes, respectively, such as in x_2^0 and x_2^*.

The multiattribute utility function can be created using the basic expansion theorem (Abbas, 2010) when there are partial utility independence (PUI) constraints. After the incorporation of the UI conditions from UDM in Fig. 3b assessed from the medical expert, the MAU function took the following form:

$$\begin{aligned} U(x_1,x_2,x_3) = {} & U(x_1^*,x_2,x_3^*)U(x_1|x_2^*,x_3^*)U(x_3|x_1^*,x_2^*) \\ & + U(x_1^*,x_2,x_3^0)U(x_1|x_2^*,x_3^*)\overline{U}(x_3|x_1^*,x_2^*) \\ & + U(x_1^0,x_2,x_3^*)\overline{U}(x_1|x_2^*,x_3^*)U(x_3|x_1^0,x_2^*) \\ & + U(x_1^0,x_2,x_3^0)U(x_1|x_2^*,x_3^*)\overline{U}(x_3|x_1^0,x_2^*) \end{aligned} \quad (3)$$

where,

$$\overline{U}(x_3|x_1^*,x_2^*) = 1 - U(x_3|x_1^*,x_2^*) \quad (4)$$

In this MAU function, we need to assess from the DM the following terms:

$$U(x_1^*,x_2,x_3^*), U(x_1^*,x_2,x_3^0), U(x_1^0,x_2,x_3^*), U(x_1^0,x_2,x_3^0), U(x_1|x_2^*,x_3^*), U(x_3|x_1^*,x_2^*), U(x_3|x_1^0,x_2^*)$$

The assessment has shown the following results:

Following the interview findings with the decision maker, we constructed a table and formulated a utility function for the specified term: $U(x_1^*, x_2, x_3^*)$.

X Axis Title	Y Axis Title
0	0
960	0.25
1680	0.5
2160	0.75
3254	1

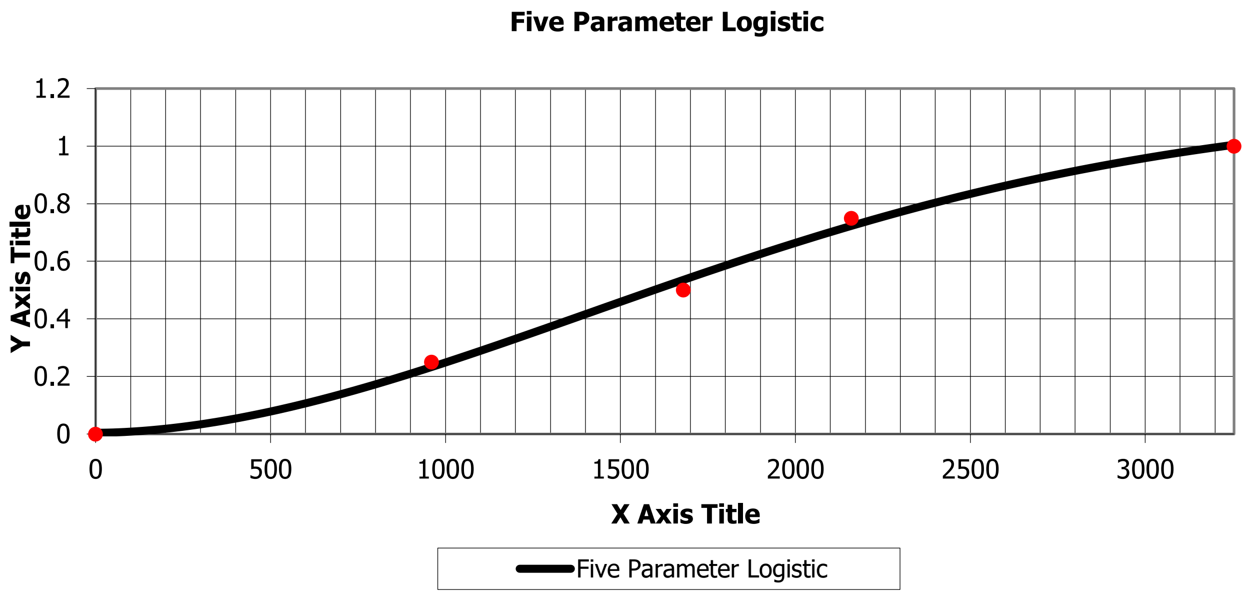


Figure 6: Fitting a curve to the evaluated (actual utility) data points for function $U(x_1^*, x_2, x_3^*)$.

Measure	Value
R²	0.996284529998815
aR²	-∞
P	
SE	∞
SSE	0.00232216875074057
F	
AIC	-14.1840728481717
BIC	-16.1368832860012
DoF	0

$$U(x_1^*, x_2, x_3^*) = 1.1374021 + \frac{0.0043461179 - 1.1374021}{[1 + (\frac{x}{1649089.5})^{1.8463053}]^{211369.74}} \quad (5)$$

Following the interview findings with the decision maker, we constructed a table and formulated a utility function for the specified term: $U(x_1^*, x_2, x_3^0)$.

X Axis Title	Y Axis Title
0	0
1680	0.25
2400	0.5
2760	0.75
3254	1

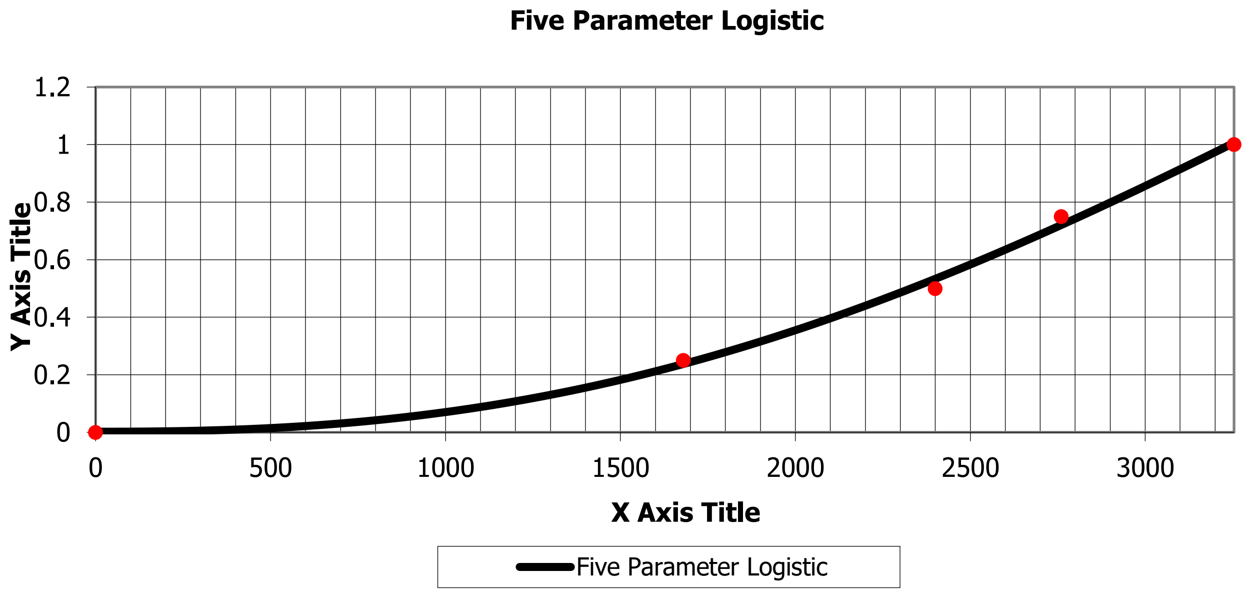


Figure 7: Fitting a curve to the evaluated (actual utility) data points for function $U(x_1^*, x_2, x_3^0)$

Measure	Value
R²	0.996493884078873
aR²	-∞
P	
SE	∞
SSE	0.00219132245070446
F	
AIC	-14.4740545232933
BIC	-16.4268649611228
DoF	0

$$U(x_1^*, x_2, x_3^0) = 2.8380897 + \frac{0.0022215658 - 2.8380897}{[1 + (\frac{x}{540724.23})^{2.4485195}]^{119575.96}} \qquad (6)$$

Following the interview findings with the decision maker, we constructed a table and formulated a utility function for the specified term: $U(x_1^0, x_2, x_3^*)$.

X Axis Title	Y Axis Title
0	0
960	0.25
1680	0.5
2040	0.75
3254	1

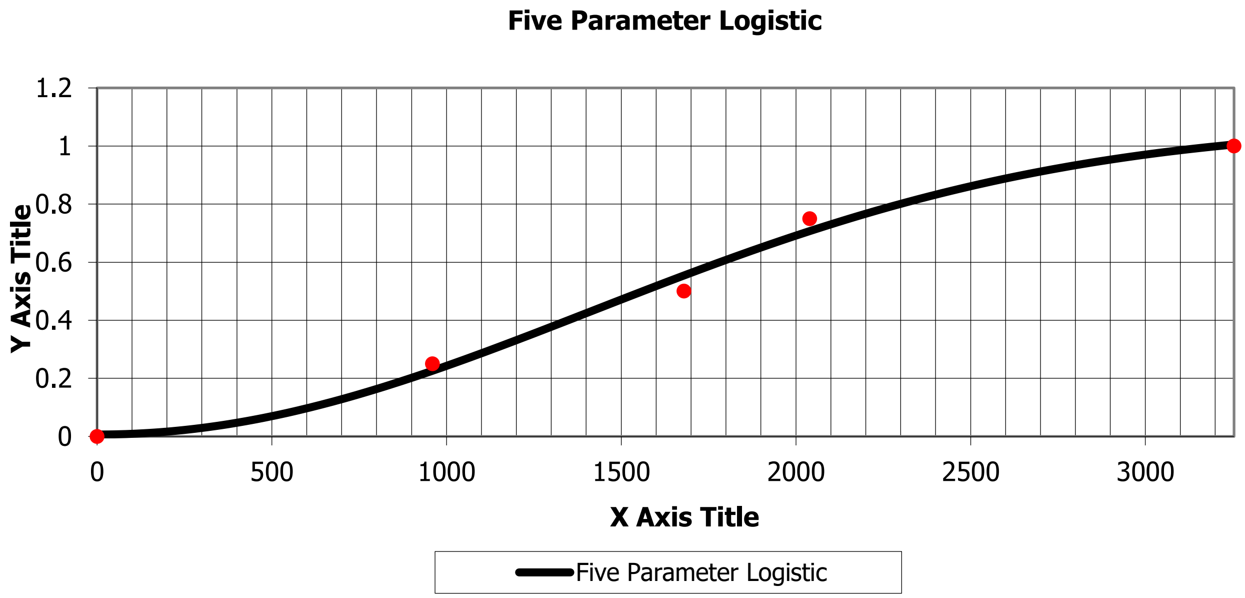


Figure 8: Fitting a curve to the evaluated (actual utility) data points for function: $U(x_1^0, x_2, x_3^*)$.

Measure	Value
R²	0.991330390985147
aR²	-∞
P	
SE	∞
SSE	0.00541850563428314
F	
AIC	-9.94748030401556
BIC	-11.9002907418451
DoF	0

$$U(x_1^0, x_2, x_3^*) = 1.0714433 + \frac{0.0066709782 - 1.0714433}{\left[1 + \left(\frac{x}{1190957}\right)^{2.037712}\right]^{465025.91}} \quad (7)$$

Following the interview findings with the decision maker, we constructed a table and formulated a utility function for the specified term: $U(x_1^0, x_2, x_3^0)$.

X Axis Title	Y Axis Title
0	0
1680	0.25
2400	0.5
2880	0.75
3254	1

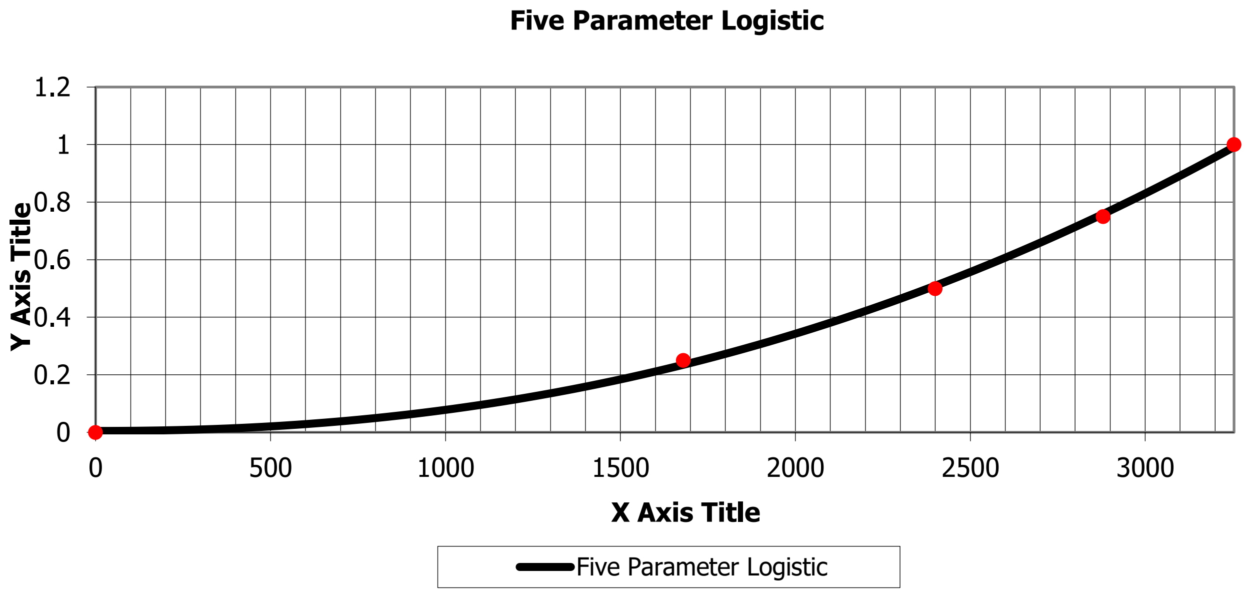


Figure 9: Fitting a curve to the evaluated (actual utility) data points for function $U(x_1^0, x_2, x_3^0)$.

Measure	Value
R^2	0.999205331038053
aR^2	-∞
P	
SE	∞
SSE	0.000496668101217042
F	
AIC	-21.8957470268267
BIC	-23.8485574646562
DoF	0

$$U(x_1^0, x_2, x_3^0) = 5845.0496 + \frac{0.0048378124 - 5845.0496}{[1 + (\frac{x}{44362.359})^{2.2052529}]^{0.053736436}} \quad (8)$$

Following the interview findings with the decision maker, we constructed a table and formulated a utility function for the specified term: , $U(x_1|x_2^*, x_3^*)$.

X Axis Title	Y Axis Title
0	0
2500000	0.25
3800000	0.5
4700000	0.75
7496000	1

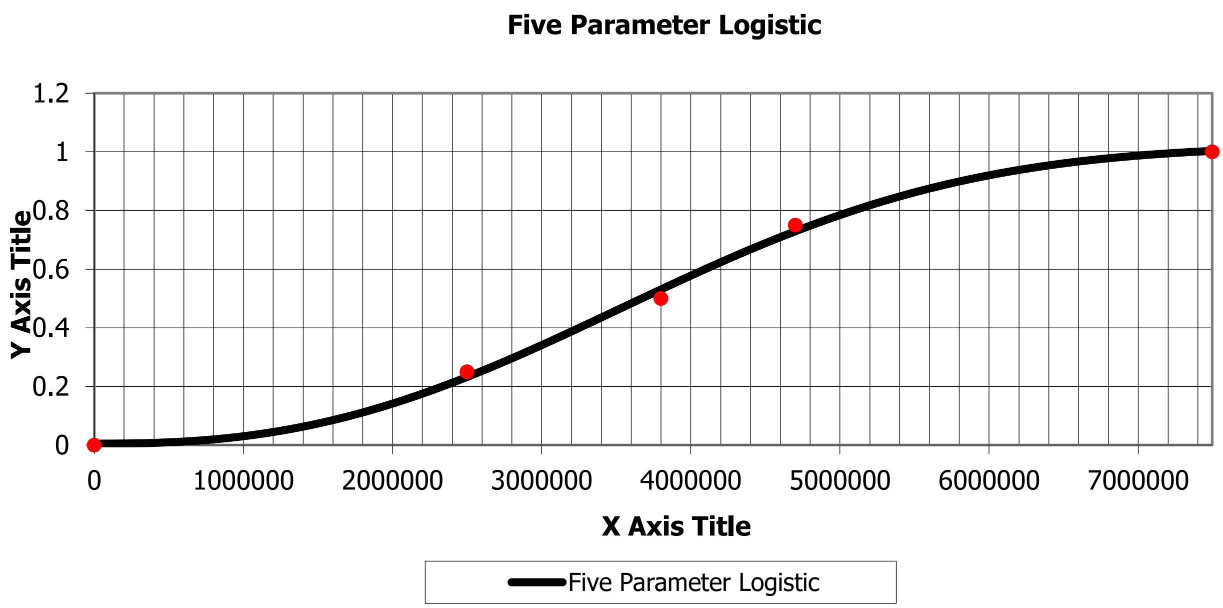


Figure 10: Fitting a curve to the evaluated (actual utility) data points for function $U(x_1|x_2^*, x_3^*)$.

Measure	Value
R²	0.997209328287053
aR²	-∞
P	
SE	∞
SSE	0.0017441698205917
F	
AIC	-15.6151871503409
BIC	-17.5679975881704
DoF	0

$$U(x_1|x_2^*, x_3^*) = 1.0207859 + \frac{0.0049153858 - 1.0207859}{[1 + (\frac{x}{222452340})^{2.5247176}]^{21142.084}} \quad (9)$$

Following the interview findings with the decision maker, we constructed a table and formulated a utility function for the specified term: $U(x_3|x_1^*, x_2^*)$.

X Axis Title	Y Axis Title
0	0
10	0.25
16	0.5
20	0.75
25	1

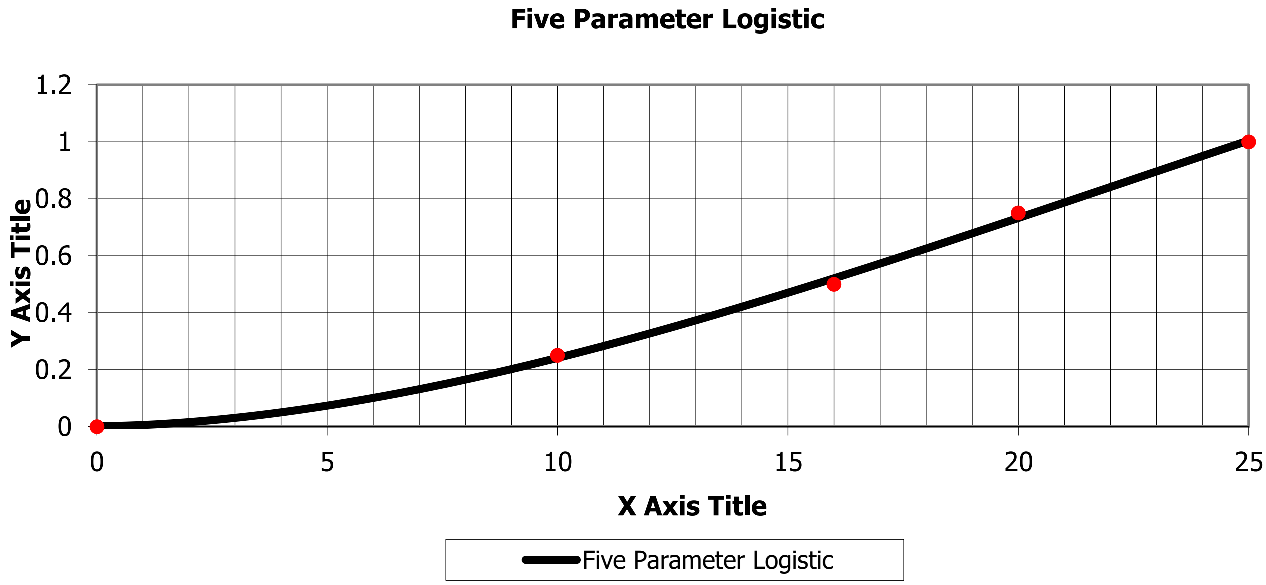


Figure 11: Fitting a curve to the evaluated (actual utility) data points for function $U(x_3|x_1^*, x_2^*)$.

Measure	Value
R²	0.998662727213677
aR²	-∞
P	
SE	∞
SSE	0.000835795491451928
F	
AIC	-19.2934372414018
BIC	-21.2462476792312
DoF	0

$$U(x_3|x_1^*, x_2^*) = 2.3880566 + \frac{0.0015504509 - 2.3880566}{[1 + (\frac{x}{37350.861})^{1.7889595}]^{260137}} \quad (10)$$

Following the interview findings with the decision maker, we constructed a table and formulated a utility function for the specified term: $U(x_3|x_1^0, x_2^*)$.

X Axis Title	Y Axis Title
0	0
8	0.25
14	0.5
18	0.75
25	1

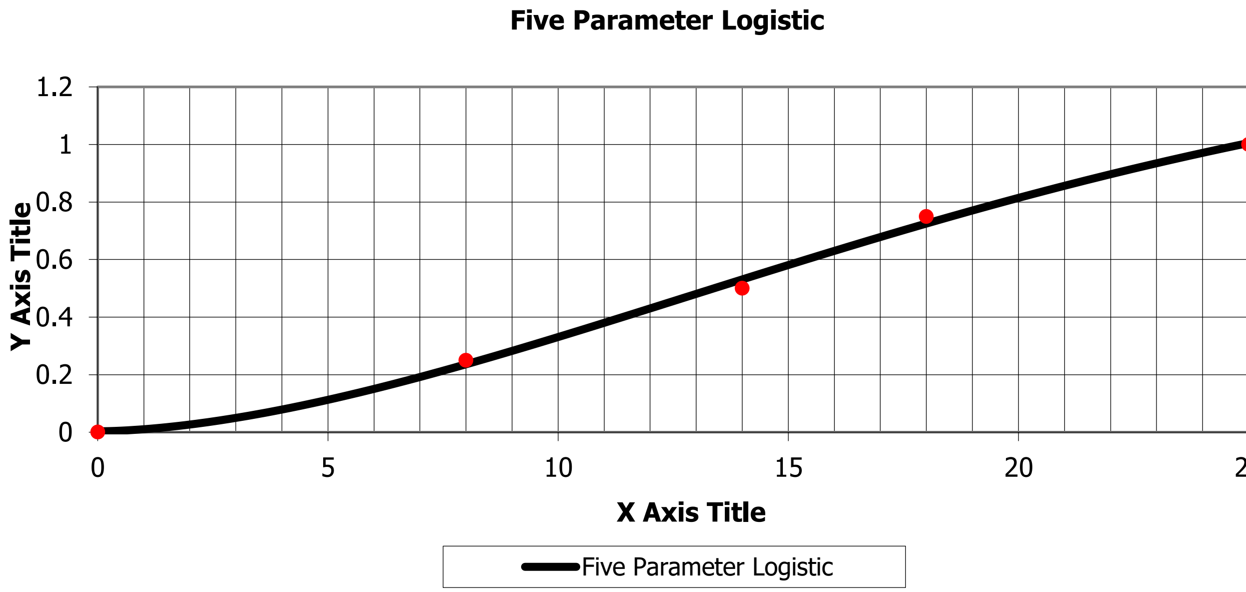


Figure 12: Fitting a curve to the evaluated (actual utility) data points for function $U(x_3|x_1^0, x_2^*)$.

Measure	Value
R²	0.997107886482068
aR²	-∞
P	
SE	∞
SSE	0.00180757094870774
F	
AIC	-15.4366609916469
BIC	-17.3894714294764
DoF	0

$$U(x_3|x_1^0, x_2^*) = 1.3701224 + \frac{0.0030758215 - 1.3701224}{[1 + (\frac{x}{49895.524})^{1.7161175}]^{608051.37}} \quad (11)$$

Figures 4-10 clearly represents curve fittings of functions
$U(x_1^*, x_2, x_3^*), U(x_1^*, x_2, x_3^0), U(x_1^0, x_2, x_3^*), U(x_1^0, x_2, x_3^0), U(x_1|x_2^*, x_3^*), U(x_3|x_1^*, x_2^*), U(x_3|x_1^0, x_2^*),$
which allow as to calculate overall MAU function for each alternative.

The construction of the MAU function under partial utility independence involves the following steps:
1. Evaluate decision maker's preferences using the formal method outlined in (Abdildin, 2014; Abdildin & Abbas, 2013) and represent them with a utility dependence matrix.
2. Determine the MAU function form from the utility dependence matrix using the basic expansion Theorem. Incorporate assessed partial utility independence criteria (Abdildin, 2014).
3. Gather necessary specifications for the MAU function from the decision maker, as detailed in the Appendix 1.
4. Substitute these specifications into the MAU functional equation and rank order alternatives based on expected utility value.

4.3.3 Ranking of the options under conditions of evaluated partial utility independence

Table 10: The order of alternatives under PUI condition

Rank order	Alternatives	E-value of U-value
#1	Airplane	0.930
#2	Helicopter	0.885
#3	Ambulance	0.611
#4	Clinical Cars	0.569
#5	Train	0.559

The expected utility of each alternative has been calculated using the MAU function (table 9). Then, the rank-order of alternatives for the given problem has been developed. While airplanes and helicopters are placed as preferred transportation modes for transferring critically ill patients with CVD, trains have taken the last rank-order in the list with an expected utility value of 0.559.

The findings presented in this chapter offer a comprehensive comparison of transportation alternatives for critically ill cardiovascular patients, evaluated under both utility independence and partial utility independence assumptions. The ranking of options led by airplane and helicopter transport highlights the critical importance of speed and clinical safety in determining preferred modes. Moreover, the divergence between single-attribute evaluations and multiattribute utility rankings underscores the necessity of considering trade-offs in complex decision environments. Having established the quantitative outcomes of the model, the next chapter turns to a deeper interpretation of these results. The Discussion will examine the broader implications for emergency healthcare logistics, compare the findings with existing literature, and explore the potential for practical implementation within Kazakhstan's health system and beyond.

Chapter 5 Discussion

The results derived from the PUI-based MAUT model, reflecting the decision maker's (DM's) preferences without assuming full utility independence, ranked the alternatives in the following order: airplane, helicopter, ambulance, clinical cars, and train. This contrasts sharply with the rankings under the UI assumption and the single-attribute evaluation based solely on transportation cost.

Our analysis showed that without explicitly modeling attribute interdependencies, the UI and single-attribute approaches produced rankings that diverged significantly from the preferences expressed by the DM. Specifically, the UI model underestimated the importance of time and safety in comparison to cost, whereas the cost-based single-attribute model misleadingly prioritized the least expensive options, such as train and clinical cars. These differences underscore the importance of using methods like PUI-based MAUT that can capture complex trade-offs in high-stakes, real-world decision scenarios.

In Table 10, we present a comparison of the outcomes obtained from three different approaches: the MAU function assessed from the DM (partial utility independence), the approach based on UI assumption, and a single criteria ranking (transportation cost saving). When evaluating the options for solving the transportation of critically ill patients with CVD problems based solely on transportation cost savings, it is evident that transporting via train is the least costly alternative, while airplane mode is the most expensive approach.

Let us examine the outcomes using the evaluated PUI circumstances and attribute supremacy conditions. Following the decision maker's preferences, the most favorable option is the airplane, while the train remains the least favorable. The helicopter was placed as the second most favorable option, with the ambulance and clinical car transportation being less preferred. It is evident that the other two approaches yield different rankings. By employing these methods, none of the options align with the ranking established by the MAU function when considering the expert's preferences. Thus, without assessing the conditions of dependence among the attributes, the decision maker may choose suboptimal alternatives.

Apart from cost, travel duration, and patient health risk, factors like patient comfort and the availability of medical staff are vital in deciding the best means of transportation for critically sick patients. Patient comfort affects physiological stability; smoother, roomier transportation options could help to lower stress and the risk of issues. Similarly, early medical intervention made possible by the availability of specialist medical professionals during transportation is vital for controlling possible difficulties in route. Although our present model emphasizes basic logistical aspects, future versions could include these other elements to improve the model's applicability and offer a more all-encompassing framework for decisions on critical care transportation. Our methodological triangulation employing three decision models adds robustness to our conclusions. The PUI-based model served as the central analytical tool, while the UI and single-attribute models acted as benchmarks. This multi-layer approach not only verified the internal consistency of our results but also highlighted the dangers of oversimplified decision-making in emergency care. In particular, our analysis demonstrates that utility-based rankings are highly sensitive to how preferences and dependencies are modeled. This finding reinforces the caution issued by (Dyer et al., 1998) and (Edwards & Newman, 2025), who warned that misuse of additive utility models can result in distorted outcomes when attribute dependencies are significant.

Although this study mostly addresses Kazakhstan's transportation and healthcare sectors, the model can be modified for other nations by adjusting criteria and decision-making guidelines to local settings. Important areas for adaptation are the organization of emergency response systems, the availability and expense of different means of transportation, and degrees of medicalization among the several possibilities. In nations with heavily urbanized areas and large air ambulance networks, for instance, the model might give air transportation options top priority different than in locations with restricted air access.

Comparisons with like approaches applied in different countries help to highlight this flexibility even further. For rural populations, for example, transport methods in countries like Australia, which deals with comparable issues with remote patient transfer, emphasize fast air medical services. Alternatively, areas with dense populations and developed ground transportation systems, like European countries, may adapt the model to prioritize the ambulance services for shorter distances. Our multiattribute utility framework offers a versatile framework that could apply in various healthcare settings when these aspects are modified and therefore allow stakeholders to make data-informed transport decisions that reflect local needs and restrictions. The practical findings of our study are also aligned with literature on air medical services and critical patient logistics. (Floccare et al., 2013) reviewed emergency air medical services (EAMS) and emphasized that response time and patient condition stability are more significant than cost in determining the appropriate mode of transport - insights that our decision maker echoed in prioritizing air-based modes. Similarly, a study by (Delgado et al., 2013) also found that helicopter transport was linked to improved survival in trauma, despite the higher cost. This aligns with our finding that the helicopter ranked second, after airplanes, due to its favorable balance between speed and operational feasibility. In contrast, while rail and road transport are often promoted in low- and middle-income countries due to cost advantages (WHO, 2023), our results highlight their limitations when evaluated through a multiattribute lens that includes clinical urgency and physiological risk. For instance, the APACHE II scoring system used to measure over the course of several days in order to determine the optimal time point for the APACHE II score in the process of forecasting the mortality of critically sick patients (Tian et al., 2022).

Our study has some limitations even if it offers insightful analysis of the decision-making process for moving critically ill cardiovascular patients. The reliance on expert assessments for data collecting and utility ratings raises one possible constraint. Expert judgment is by nature subjective, hence differences in experience or viewpoint could inject prejudice into the assessment of different transportation choices and qualities. Our questionnaires have a mechanism for checking the consistency of answers, but some degree of subjectivity may still influence the results.

Furthermore, our model is developed for Kazakhstan's transportation and healthcare systems. Although the multiattribute utility function design can be modified to fit other areas, the data, including infrastructure, medical capacity, and transportation expenses, may vary greatly abroad. Applying the concept in various settings would thus need changes to consider local conditions and resources. Future studies should investigate these modifications by means of pilot studies in different geographic and healthcare environments, therefore enhancing the general relevance of the model.

Table 11: The rank-order of alternatives assessed by three methods

Rank order	Methods		
	MUF under assessed PUI conditions	MAU under utility independence assumption	Ranking based on transportation cost savings
#1	Airplane	Train	Train
#2	Helicopter	Helicopter	Ambulance
#3	Ambulance	Ambulance	Clinical cars
#4	Clinical Cars	Airplane	Helicopter
#5	Train	Clinical cars	Airplane

According to (Abbas, 2018) and (R. L. Keeney et al., 1979) where both emphasized that MAUT is especially effective when preferences must be evaluated under uncertainty and with multiple, conflicting objectives. In our study, attributes such as cost, time, and safety were not only critical but also interconnected.

From a theoretical perspective, our work contributes to the literature on utility function construction under partial utility independence. By employing the Basic Expansion Theorem and Utility Dependence Matrix (UDM) (Abbas, 2010), we captured the nuanced interplay among attributes without overburdening the assessment process. This methodological advancement builds on previous work by (Abbas & Howard, 2005), offering a practical pathway for preference-sensitive decision modeling in domains where full independence assumptions are often violated. Our results provide empirical evidence that real-world decisions especially those involving life-or-death trade-offs cannot be adequately captured using simplified assumptions. Our findings are consistent with those of (Abdildin & Abbas, 2016), who used a PUI-based MAUT model to optimize uranium filter restoration, showing that functional multiattribute forms significantly outperformed traditional additive utility models in capturing real decision-maker behavior. Like their work, we found that relaxing the UI assumption allows for a more accurate and context-sensitive representation of stakeholder preferences. This study provides actionable insights for healthcare policy makers and emergency logistics coordinators in Kazakhstan and other countries with similar geographical and infrastructural constraints. The incorporation of APACHE II scores into transportation decision models introduces a medically grounded measure of safety that can be integrated into national triage protocols. Currently, NCCEM uses a categorical triage system (green/yellow/red) that lacks granularity. By shifting to APACHE II-based assessment, healthcare providers can make more informed and individualized transport decisions. Additionally, our findings suggest that investment in air transportation infrastructure specifically expanding helicopter services and improving airstrip access in remote areas would align with the preferences of medical professionals and improve patient outcomes. These insights could guide the allocation of healthcare transport budgets and influence policy regarding the certification of private clinical transport providers.

The transportation of critically ill patients with cardiovascular diseases (CVD) in large, sparsely populated countries like Kazakhstan is a multidimensional decision problem requiring the integration of clinical, economic, and logistical factors. In this study, we developed a decision support framework based on Multiattribute Utility Theory (MAUT) to evaluate five transportation alternatives: airplane, helicopter, ambulance, train, and clinical cars. Our approach incorporated three primary analytical methodologies MAUT under partial utility independence (PUI), MAUT under utility independence (UI), and a single-attribute evaluation method.

Currently, the model contains three main attributes that reflect the decision-maker's primary trade-offs: cost, time and safety. However, there are many other factors that can affect transport decisions, such as the availability of trained specialized crews for each mode of transport, the extent to which equipment is standardized between sending and receiving facilities, and the level of established air, rail and sea infrastructures serving remote areas. In future models, these factors can be addressed in two distinct ways:

a) As additional attributes within the MAUT multiattribute utility function, forming a more extensive criterion vector that will take into account the complexity of operations.

b) By using those to determine the "patient safety" factor in the PA-II risks associated with transport; e.g., by adjusting the expected patient risk based on the availability of specialist crews and infrastructure. In both situations, the general flexibility of a MAUT allows these additional criteria/factors to be incorporated and for the trade-offs to be recalculated as data becomes available and judgment is established.

In summary, our work not only affirms the value of MAUT in complex healthcare logistics but also contributes to the refinement of decision modeling techniques under partial independence. The next chapter presents the overall conclusions, implications for practice, and future research directions. This chapter presents a comprehensive discussion of our findings, drawing comparisons with existing literature and highlighting the theoretical and practical implications of our multi-method analysis.

Chapter 6 Conclusion

In conclusion, we developed a multiattribute model for addressing the complex decision problem of transporting critically ill patients with cardiovascular disease. We also compared three different methods based on the decision maker's preferences, UI assumptions, and single criteria. The assessed expert preferences (partial utility independence conditions) demonstrated the following rank-order of alternatives: airplane, helicopter, ambulance, clinical cars, and train. The assumptions of UI yielded a different ranking. When one attribute (transportation expenses) is considered, the rank order of alternatives is listed from the cheapest mode to the most expensive one.

Our comparative analysis revealed disparities in rankings when considering transportation options based solely on transportation cost savings. When three attributes are being considered, the DM has faced some challenges with the assumption of UI among the attributes. The decision maker's preferences satisfy the partial utility independence conditions. Our study emphasizes the importance of accurately reflecting the decision maker’s preferences.

The practical aspect of our model is yet to be evaluated. We believe that our model will help the national healthcare system to reduce transportation time, transportation expenses, and minimize the adverse health effects.

Future research might incorporate case studies or pilot experiments proving the model's usefulness in real-world situations, hence stressing its practical relevance. Such uses would enable us to demonstrate the decision-making process and results while moving critically ill cardiovascular patients, therefore offering concrete illustrations of the value of the model. Moreover, interacting with important players such policy advisers, emergency response teams, and medical professionals will present chances for cooperation and ongoing development. Including comments from those directly involved in patient transportation logistics helps the model to be improved to better handle pragmatic issues and change with the needs of the healthcare system.

Moving patients with cardiovascular disease (CVD) who are very sick is not just a logistical issue; it is also a critical decision-making issue that requires balancing clinical urgency, resource optimization, and public health equity. This study used Multiattribute Utility Theory (MAUT) to make a strong, structured decision analysis framework, with a focus on modelling partial utility independence (PUI). The study's goal was to use expert opinions, real-world data, and methodological triangulation to make a clear, flexible, and evidence-based decision support model for moving emergency patients in Kazakhstan. This chapter gives a quick summary of the research's goals, main findings, and what they mean in real life and in theory. It also talks about the study's flaws and suggests ways for future research to make the proposed model more useful and have a bigger impact.

6.1 Summary of Research Objectives and Methodologies

The core objective of this research was to design and apply a preference-sensitive, multiattribute decision-making model that could assist in choosing optimal transportation modes for critically ill cardiovascular patients. The research was guided by the following primary goals:

To identify and quantify key decision attributes affecting transport mode selection: transportation cost savings (X_1), time savings (X_2), and patient safety (X_3) measured by APACHE II scores.

To assess expert preferences and derive a multiattribute utility function (MUF) under conditions of partial utility independence (PUI) using structured interviews and indifference probability methods.

To compare the PUI-based model with a utility independence (UI) model and a single-attribute evaluation method, providing a benchmark and sensitivity analysis of different modeling assumptions.

To construct a decision tree encompassing multiple scenarios and apply probabilistic analysis to compute expected utilities for each alternative.

The combination of PUI modeling, utility dependence matrix (UDM) structuring, and real-world data collection through the National Coordination Center for Emergency Medicine (NCCEM) formed the methodological backbone of this study.

6.2 Key Findings and Contributions

6.2.1 Ranking of Alternatives and Decision Maker Preferences

Under the PUI-based MUF, which allowed interdependencies between attributes, the following rank order of transportation alternatives was established:

1. Airplane
2. Helicopter
3. Ambulance
4. Clinical Cars
5. Train

This ranking was very close to what the decision maker would have chosen based on their gut feelings, especially when it came to putting safety and time ahead of saving money. People liked airplanes the most, even though they were the most expensive, because they took the least amount of time to travel and were more likely to keep patients stable. On the other hand, the UI-based model thought that all attributes were completely separate and came up with a different ranking. It did not put as much weight on trade-offs between attributes, which is why air-based transportation got a lower score than other types of transportation. This difference shows that thinking that utility independence is true may make complicated clinical decision-making situations too easy. Similarly, the single-attribute method, when applied to cost alone, misleadingly ranked train and clinical car options highest. This method, although useful in urgent or data-limited settings, was shown to be inadequate for nuanced decisions involving life-threatening conditions.

6.2.2 Theoretical and Methodological Contributions

Validation of PUI Modeling: The successful construction and application of a MUF under PUI confirms its utility in healthcare logistics and complements existing literature (Abbas, 2018; Abdildin & Abbas, 2013). Application of the Utility Dependence Matrix (UDM): The UDM served as a diagnostic and modeling tool, enabling systematic identification of attribute interdependencies. This validated the use of functional forms in complex decision environments. The deployment of indifference probability scenarios and structured interviews allowed the incorporation of expert knowledge into the utility function, bridging the gap between normative theory and applied decision analysis. Incorporating APACHE II as a surrogate for clinical safety ensures that the model remains grounded in biomedical realism, enhancing its credibility among healthcare professionals.

6.3 Practical Implications

Connecting the contributions to a theoretical model and its practical application, we have presented that the next logical step in evaluating the proposed approach would involve conducting an evaluation of the proposed approach within a "real" clinical setting. Our proposed design for this pilot implementation would be to conduct this pilot implementation using a small group of referral hospitals who would participate in the pilot alongside members of the NCCEM. In addition to evaluating how this approach works within a true clinical setting, during the defined pilot timeframe, dispatchers and clinicians in these hospitals would have access to an electronic worksheet (or decision support tool) containing a pre-defined multi-attribute utility function and upon each instance of an eligible case record the following-record the recommended transport modality, record the actual transport modality selected, record important process metrics (i.e., time to arrival, delays, cancellations), and record basic clinical outcomes within 24–48 hours after transport had occurred. This pilot project would provide at least three important pieces of information: It would provide evidence regarding the usability of the model under time-pressed circumstances and demonstrate the ability to use the model along with the existing workflow processes in a true clinical environment, as well as indicate if using this model to assist clinicians and dispatchers in making transport-related decisions results in more timely and safer treatment. The results of this pilot would also inform future studies regarding implementation of larger-scale evaluations utilizing this model and establish a pathway for formalizing the use of the proposed method as an element of National Emergency Transport Protocols.

This study provides actionable insights for national healthcare decision makers in Kazakhstan and similar countries with geographic, infrastructural, and resource-based challenges:

Policy-Level Decision Support: The PUI-based MUF offers a repeatable, transparent tool that can be institutionalized in healthcare transport protocols.

Resource Allocation Optimization: The ability to quantify trade-offs across cost, time, and safety supports more equitable and efficient budgetary decisions.

Integration with Clinical Triage Systems: Incorporating APACHE II into decision frameworks may improve triage prioritization by making it more data-driven and clinically sensitive.

Training and Operational Planning: The methodology can be adapted for emergency coordination training programs, giving healthcare administrators a rigorous foundation for scenario planning.

Expansion to Rural and Regional Logistics: With additional data, the model could guide investment decisions in regional healthcare infrastructure such as helipads, mobile ICUs, and road upgrades.

6.4 Limitations

Although this dissertation proposes a structured and contextually relevant decision-making framework for transporting critically ill cardiovascular patients, several limitations should be acknowledged to provide a complete perspective on the scope and applicability of the study.

First, while expert judgment formed an essential part of the utility elicitation process, the number of consulted professionals was modest due to logistical constraints. Although the insights provided were informed and clinically grounded, a wider pool of experts drawn from different regions and healthcare settings could further enrich the model's robustness and reflect broader medical practice.

The methodological foundation of this research is based on Multiattribute Utility Theory (MAUT), which assumes a rational and consistent decision-making process. In emergency situations, however, decisions are often influenced by urgency, uncertainty, and operational constraints. While the model captures complex trade-offs in a systematic way, it may not fully replicate the speed and emotional pressure inherent in real-time clinical decision-making.

This study also employs a static decision environment, where input variables such as time, cost, and patient safety are treated as stable during analysis. In practice, conditions may evolve rapidly due to weather, equipment availability, or patient deterioration. While the model offers strong analytical guidance, dynamic factors affecting transport decisions may require additional tools or real-time decision support integration in the future.

The application of the APACHE II scoring system to quantify patient severity offers a scientifically grounded alternative to triage color codes, but it also assumes the availability of detailed physiological data. In some emergency settings, particularly in rural or resource-limited areas, such detailed assessments may not be feasible. Nonetheless, the APACHE II framework provides a strong foundation for modeling patient risk in a more predictive manner than current methods in use.

It is also important to recognize that the findings of this study are most relevant to the healthcare system and logistical context of Kazakhstan. Variations in infrastructure, funding, and emergency medical protocols may affect the direct applicability of the model in other settings. However, the conceptual framework and methodological approach can be adapted and extended to other countries facing similar transport challenges.

The current research has predominantly examined the model's internal validation through assessing how consistent the responses were of the experts consulted in this study, and through comparing expert rankings from each of the three model structures (I.e., single-attribute, UI, PUI), and by examining whether the final recommended rankings reflected what experienced clinician's qualitative expectations were. However, no formal external evaluation of the model has been completed. A logical step to take would be to apply the model to retrospective subgroups (e.g., geographic regions such as Northern Oblasts; Southern Oblasts; Urban Catchment Area; Rural Catchment Area) to see if the recommended transport modes were similar to actual delivery patterns and results. Furthermore, a prospective pilot programme at the regional level could involve incorporating the model into the decision making process for certain corridors such as the Long-Distance Transport from Western Kazakhstan to the Cardiac Centres in Astana and/or Almaty. The comparison of process and patient output indicators between those routes and those using the current decision making process would result in a measurable confirmation of the robustness and practical utility of the model in various geographical and infrastructural contexts.

Lastly, while the decision model has demonstrated strong internal logic and consistency, it has not yet been piloted in real-world clinical settings. Future applications involving collaboration with emergency services, dispatch centers, or health authorities will be important to validate its practical impact and usability.

Overall, these limitations do not detract from the contributions of the study but instead highlight opportunities for further refinement and future research. The framework presented here provides a valuable step toward evidence-based, transparent decision-making in critical care transport, and its potential can be further enhanced through interdisciplinary collaboration and technological integration.

6.5 Future Work

Building upon the findings and structure of this dissertation, several promising directions for future research and development are evident. As healthcare systems continue to evolve and face increasing logistical complexity, particularly in large and sparsely populated countries like Kazakhstan, decision-support tools such as the one proposed here can benefit from further enhancement and broader integration.

One important avenue for future work involves expanding the expert elicitation process. Including a more diverse group of stakeholders such as cardiologists, emergency physicians, transport dispatchers, health economists, and even patients or patient advocates would provide a more comprehensive perspective on transportation priorities and risk tolerance. This could improve the model’s representativeness and ensure that it captures the values and preferences of all parties involved in emergency decision-making. Another key direction is the implementation of dynamic decision models. While the current framework operates under static assumptions for analytical clarity, future studies could incorporate real-time data feeds (e.g., GPS location, weather conditions, resource availability, and patient vitals) to support adaptive and context-sensitive decision-making. This could be achieved through integration with digital health platforms, clinical dashboards, or mobile applications used by emergency dispatch centers.

Further research could also explore multi-stakeholder decision environments, where decisions are influenced not only by clinical needs but also by budget constraints, regulatory policies, and regional service availability. Extending the model to accommodate multi-criteria optimization across different institutions or healthcare levels (e.g., regional hospitals, national centers, and rural clinics) would enhance its relevance in coordinated care systems.

The development of training modules or decision-support tools based on this model also represents a practical step forward. Putting the decision framework into the standard operating procedures of Kazakhstan's emergency medical services or national coordination centers could help policies get carried out and operations run more smoothly. Pilot testing these kinds of tools in certain areas and getting feedback in a structured way would show that they work and support their long-term use in institutions.

Lastly, more research could look into how this framework might be useful in other areas besides heart health. The model could also be used in other serious situations, such as a stroke, a traumatic injury, or an emergency with a newborn, where time, cost, and safety are still the most important things to think about when making decisions. We could learn more about whether trade-offs related to transportation are the same in all clinical settings or only in some by comparing them.

In order to carry out these future directions, a few Methodological Steps will be required to operationalise them. The first of these will be a prospective pilot study in conjunction with the NCCEM to evaluate a limited number of “real” cases using a MAU model, at the point at which “transport” decisions were being made. The mode of transport recommended for each case, as well as the mode actually chosen by the emergency medical services (EMS), along with the respective outcomes (clinical) and transport process indicators (total time taken for transport, etc.) will be recorded. Comparison of “model-consistent” and “model-inconsistent” decisions will thus be possible, providing an initial assessment of face validity, usability and possible clinical impact of the framework.

The second methodological direction for future research is to create a dynamic, data-driven decision support tool. This would involve the continuous updating of real-time data (such as GPS-based travel times, aircraft and ground ambulance availability, weather, and APACHE II scores) into an electronic dashboard for use by dispatchers and clinicians. The multiattribute utility function used to derive decisions would remain conceptually similar to that described in this study, although attributes and their corresponding scaling parameters would be updated automatically when this information becomes available. This would provide dispatchers and clinicians with ongoing, or "living," decision-making support that reflects the ever-changing nature of clinical care.

In short, the foundational model made in this dissertation gives us a lot of new ways to look at things, both in terms of practice and research. By expanding its scope, adding real-time responsiveness, and showing that it can be used in real-world situations, future work can help make the healthcare logistics system fairer, efficient, and based on evidence.

6.6 Final Remarks

In conclusion, this dissertation gives you a structured, evidence-based decision analysis framework that is made to help with the hard job of transporting critically ill heart patients. By applying multiattribute utility theory under conditions of partial utility independence, the study offers a nuanced understanding of the trade-offs between cost, time, and clinical risk in emergency transport scenarios. The methodological rigor, combined with contextual relevance to Kazakhstan’s healthcare system, positions this work as both a theoretical contribution and a practical guide for improving health service delivery. While limitations exist, they also open avenues for future research and refinement. Ultimately, this study aspires to support more informed, transparent, and patient-centered decision-making in critical care logistics is not only in Kazakhstan but also in other health systems navigating similar geographic and systemic challenges.

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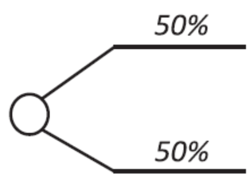
Appendices

Appendix 1

Defining the utility function for attribute X_1 (savings on transportation costs) for transporting patients with critical cardiovascular diseases (in tenge).

In the tests below, please fill in the blanks (____) with the amount of money in tenge, X_1, so that you are indifferent between saving this amount from transporting a patient or choosing the amount randomly on the right side.

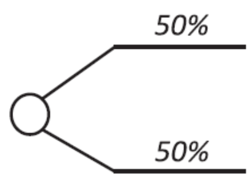
(1) $X_{0.50}$ = ____________ KZT ~
(your answer)



7 496 000 KZT

0 KZT

(2) $X_{0.75}$ = ____________ KZT
(your answer)

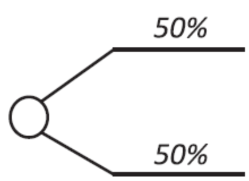


7 496 000 KZT

_____________ KZT

put $X_{0.50}$ from (1)

(3) $X_{0.25}$ = ____________ KZT
(your answer)

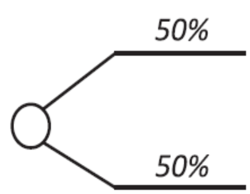


_____________ KZT

put $X_{0.50}$ from (1)

0 KZT

(4) X_{check} = ____________ KZT ~
(your answer)



_____________ KZT

put $X_{0.75}$ from (2)

_____________ KZT

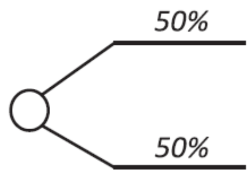
put $X_{0.25}$ from (3)

Appendix 2

Definition of the Utility Function for Attribute X_2 (Time Savings on Transportation) for Transporting Patients with Critical Cardiovascular Conditions (in Minutes)

In the tests below, please write in the blanks (____) the amount of time in hours, X_2, such that you are indifferent between the time savings on transporting the patient or choosing the transportation time randomly from the right side.

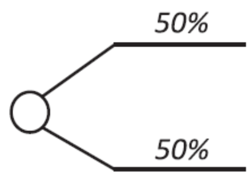
(1) $X_{0.50}$ = _________ mins ~
(your answer)



3254 min

0 min

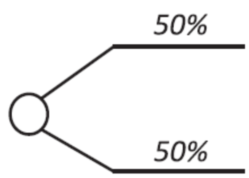
(2) $X_{0.25}$ = __________ mins ~
(your answer)



_____________ mins
put $X_{0.50}$ from (1)

0 min

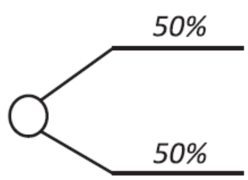
(3) $X_{0.75}$ = __________ mins ~
(your answer)



3254 mins

_____________ mins
put $X_{0.50}$ from (1)

(4) X_{check} = __________ mins ~
(your answer)



_____________ mins
put $X_{0.75}$ from (3)

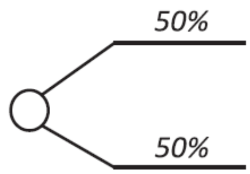
_____________ mins
put $X_{0.25}$ from (2)

Appendix 3

Definition of the Utility Function for Attribute X_3 (Impact of Transportation on Patient's Health) for Transporting critically ill patients with cardiovascular disease (Assessed in Points According to the APACHE II Health Scoring System)

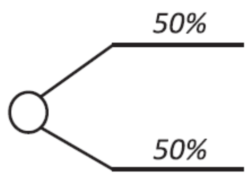
In the tests below, please write in the blanks (____) the number, X_3, such that you are indifferent between the patient's condition worsening by this number during transportation or by the number chosen randomly from the right side.

(1) $X_{0.50}$ = ____________ ~
(your answer)



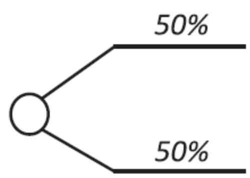
25
1

(2) $X_{0.75}$ = ____________ ~
(your answer)



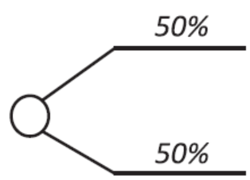
25
____
put $X_{0.50}$ from (1)

(3) $X_{0.25}$ = ____________ ~
(your answer)



____
put $X_{0.50}$ from (1)
1

(4) X_{check} = ____________ ~
(your answer)



____
put $X_{0.75}$ from (2)
____
put $X_{0.25}$ from (3)

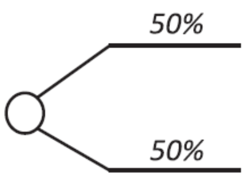
Appendix 4

Question 1. Dependence of Transportation Time Saving (X_2) on Costs Savings on Transportation (X_1)

a) There are two cases, A and B, and in each case, there are two options for the transportation time of the patient, which can occur with equal probability (50/50). Which case would you prefer in Scenario 1?

Scenario 1: In both cases, X_1^* = 7 496 000 KZT (transportation cost saving)

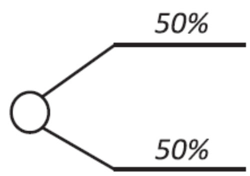
A:



X_2^* = 3254 mins

X_2^0 = 0 min

B:



720 mins

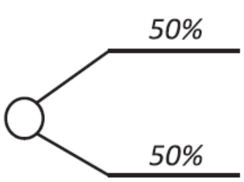
1440 mins

Choose one of the three options**:**	*Case A*	Indifferent (A and B are the same)	*Case B*

b) Which case would you prefer in Scenario 2?

Scenario 1: In both cases, X_1^0 **= 0 KZT** (transportation cost saving)

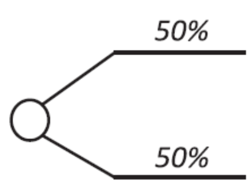
A:



X_2^* = 3254 mins

X_2^0 = 0 min

B:



720 mins

1440 mins

Choose one of the three options**:**	*Case A*	Indifferent (A and B are the same)	*Case B*

c) If the value of attribute X_1 in Scenario 1 (or Scenario 2) were fixed at some other value between X_1^* and X_1^0, would your answer change?

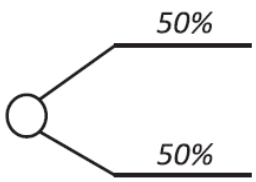
Choose one: *Yes* *No*

Question 2. Dependence of Savings Costs on Transportation (X_1) on Transportation Time Saving (X_2)

a) There are two cases, A and B, and in each case, there are two options for the cost of transporting the patient, which can occur with equal probability (50/50). Which case would you prefer in Scenario 1?

Scenario 1: In both cases, $X_2^* = 3{,}254$ minutes (time saving on transportation)

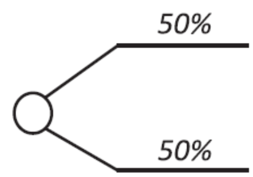
A:



$X_1^* = 7\ 496\ 000$ KZT

$X_1^0 = 0$ KZT

B:



5 million KZT

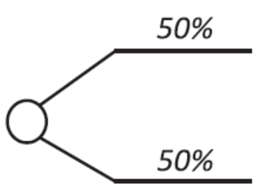
2 million KZT

Choose one of the three options**:**	*Case A*	Indifferent (A and B are the same)	*Case B*

b) Which case would you prefer in Scenario 2?

Scenario 2: In both cases, $X_2^0 = 0$ minutes (time savings on transportation)

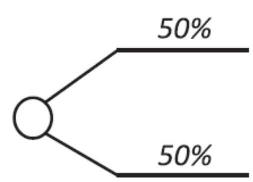
A:



$X_1^* = 7\ 496\ 000$ KZT

$X_1^0 = 0$ KZT

B:



5 million KZT

2 million KZT

Choose one of the three options**:**	*Case A*	Indifferent (A and B are the same)	*Case B*

c) If the value of attribute X_2 in Scenario 1 (or Scenario 2) were fixed at some other value between X_2^* and X_2^0, would your answer change?

Choose one: *Yes* *No*

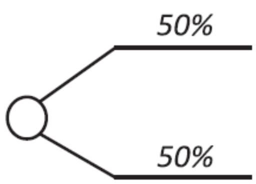
Appendix 5

Question 1. Dependence of Savings Costs on Transportation (X_1) on the Impact of Transportation on Health (X_3)

a) There are two cases, A and B, and in each case, there are two options for the cost of transporting the patient, which can occur with equal probability (50/50). Which case would you prefer in Scenario 1?

Scenario 1: In both cases, X_3^* = 25 (impact of transportation on health)

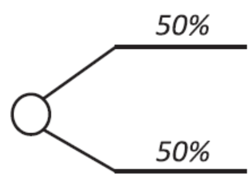
A:



X_1^* = 7 496 000 KZT

X_1^0 = 0 KZT

B:



5 million KZT

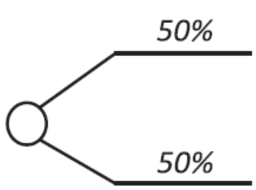
2 million KZT

Choose one of the three options**:**	*Case A*	Indifferent (A and B are the same)	*Case B*

b) Which case would you prefer in Scenario 2?

Scenario 2: In both cases, X_3^0 = 1 (impact of transportation on health)

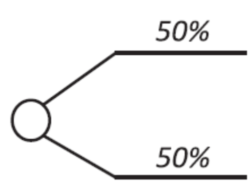
A:



X_1^* = 7 496 000 KZT

X_1^0 = 0 KZT

B:



5 million KZT

2 million KZT

Choose one of the three options**:**	*Case A*	Indifferent (A and B are the same)	*Case B*

c) If the value of attribute X_3 in Scenario 1 (or Scenario 2) were fixed at some other value between X_3^* and X_3^0, would your answer change?

Choose one: *Yes* *No*

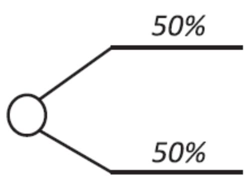
Question 2. Dependence of the Impact of Transportation on Health (X_3) on Saving Cost on Transportation (X_1)

a) There are two cases, A and B, and in each case, there are two options for the impact of transportation on the patient's health, which can occur with equal probability (50/50). Which case would you prefer in Scenario 1?

Scenario 1: In both cases, X_1^*= 7,496,000 KZT (savings costs on transportation)

A:

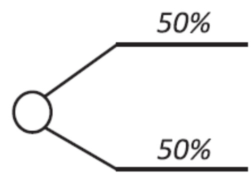
$X_3^* = 25$



$X_3^0 = 1$

B:

17



11

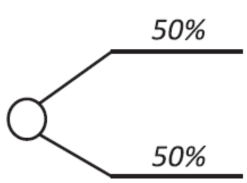
Choose one of the three options**:** *Case A* Indifferent (A and B are the same) *Case B*

b) Which case would you prefer in Scenario 2?

Scenario 2: In both cases, X_1^0 = 0 KZT (savings costs on transportation)

A:

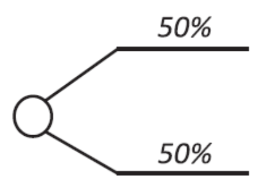
$X_3^* = 25$



$X_3^0 = 1$

B:

17



11

Choose one of the three options**:** *Case A* Indifferent (A and B are the same) *Case B*

c) If the value of attribute X_1 in Scenario 1 (or Scenario 2) were fixed at some other value between X_1^* and X_1^0, would your answer change?

Choose one: *Yes* *No* ***Choose one:***

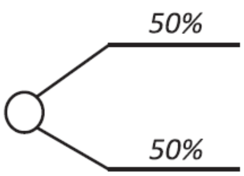
Appendix 6

Question 1. Dependence of transportation time (X_2) on the impact of transportation on health (X_3)

a) Given two cases A and B, and in each case there are two options for the time to transport the patient, which can occur with equal probability (50 to 50). Which case would you prefer in Scenario 1?

Scenario 1: in both cases X_3^* = 25 (health impact of transportation)

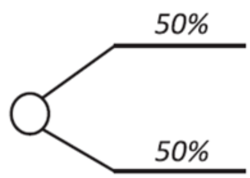
A:



X_2^* = 3254 min

X_2^0 = 0 min

B:



1440 min

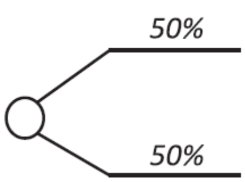
720 min

Choose one of the three options: *Case A* Indifferent (A and B are the same) *Case B*

b) Which case would you prefer in Scenario 2?

Scenario 2: in both cases X_3^0 = 1 (negative impact of transportation on health)

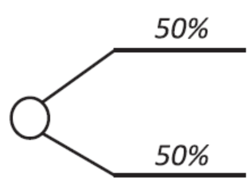
A:



X_2^* = 3254 min

X_2^0 = 0 min

B:



1440 min

720 min

Choose one of the three options: *Case A* Indifferent (A and B are the same) *Case B*

c) If the value of attribute X_3 in Scenario 1 (or Scenario 2) were fixed to some other value between X_3^* and X_3^0, would your answer change?

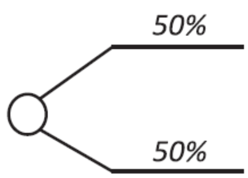
Choose one: *Yes* *No*

Question 2. Dependence of the impact of transportation on health (X_3) on transportation time (X_2)

a) Given two cases A and B, and in each case there are two options for the impact of transportation on the patient's health, which can occur with equal probability (50 to 50). Which case would you prefer in Scenario 1?

Scenario 1: in both cases X_2^* = 3254 min (saving transportation time)

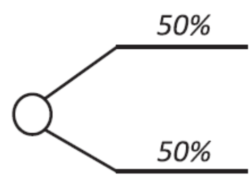
A:



$X_3^* = 25$

$X_3^0 = 1$

B:



17

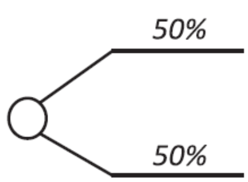
11

Choose one of the three options:	*Case A*	Indifferent (A and B are the same)	*Case B*

b) Which case would you prefer in Scenario 2?

Scenario 2: in both cases $X_2^0 = 0$ min (transport time saved)

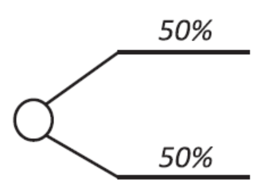
A:



$X_3^* = 25$

$X_3^0 = 1$

B:



17

11

Choose one of the three options:	*Case A*	Indifferent (A and B are the same)	*Case B*

c) If the value of attribute X_2 in Scenario 1 (or Scenario 2) were fixed to some other value between X_2^* and X_2^0, would your answer change?

Choose one: *Yes* *No*

Appendix 7

Questionnaire for Determining Constant Parameters

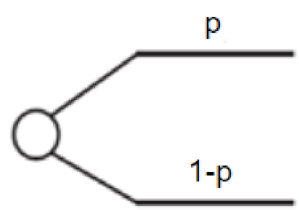
What probability (p) will cause you to remain indifferent between saving 74960000 KZT on transportation costs and 0 minute of transportation with a negative effect of 0 and choosing randomly between spending 7,496,000 KZT and 3,254 minutes of transportation with a negative effect of 25 with probability p and spending 0 KZT and 0 minutes of transportation with a negative effect of 0 with probability (1-p)?

Answer: k1 = $U(x_1^*, x_2^0, x_3^0)$ = ______

TCS: 7 496 000 KZT
Time saving: 3254 mins
Heath effect: 25

TCS: 7 496 000 KZT
Time saving: 0 min
Heath effect: 0

~



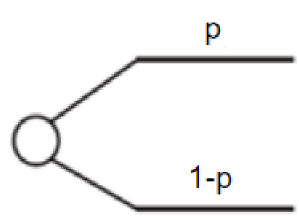
TCS: 0 KZT
Time saving: 0 min
Heath effect: 0

What probability (p) will cause you to remain indifferent between saving 0 KZT on transportation costs and 3254 minutes of transportation with a negative effect of 0 and choosing randomly between spending 7,496,000 KZT and 3,254 minutes of transportation with a negative effect of 25 with probability p and spending 0 KZT and 0 minutes of transportation with a negative effect of 0 with probability (1-p)?

Answer: k2 = $U(x_1^0, x_2^*, x_3^0)$ = ______

TCS: 7 496 000 KZT
Time saving: 3254 mins
Heath effect: 25

TCS: 0 KZT
Time saving: 3254 mins
Heath effect: 0



TCS: 0 KZT
Time saving: 0 min
Heath effect: 0

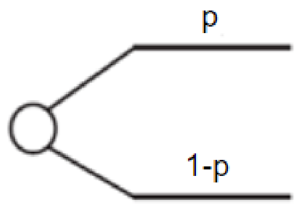
What probability (p) will cause you to remain indifferent between saving 7,496,000 KZT on transportation costs and 3,254 minutes of transportation with a negative effect of 0 and choosing randomly between spending 7,496,000 KZT and 3,254 minutes of transportation with a negative effect of 25 with probability p and spending 0 KZT and 0 minutes of transportation with a negative effect of 0 with probability (1-p)?

Answer: k3 = $U(x_1^0, x_2^0, x_3^*)$ = ______

TCS: 7 496 000 KZT
Time saving: 3254 mins
Heath effect: 25

TCS: 7 496 000 KZT
Time saving: 3254 mins
Heath effect: 0

~



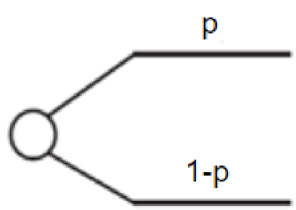
TCS: 0 KZT
Time saving: 0 min
Heath effect: 0

What probability (p) will cause you to remain indifferent between saving 7 496 000 KZT on transportation costs and 3254 minutes of transportation with a negative effect of 0 and choosing randomly between spending 7 496 000 KZT and 3,254 minutes of transportation with a negative effect of 25 with probability p and spending 0 KZT and 0 minutes of transportation with a negative effect of 0 with probability (1-p)?

Answer: $p = U(x_1^*, x_2^*, x_3^0)$ = ______

TCS: 7 496 000 KZT
Time saving: 3254 mins
Heath effect: 25

TCS: 7 496 000 KZT
Time saving: 3254 mins
Heath effect: 0



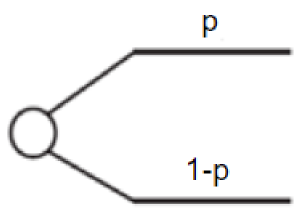
TCS: 0 KZT
Time saving: 0 min
Heath effect: 0

What probability (p) will cause you to remain indifferent between saving 7 496 000 KZT on transportation costs and 0 minute of transportation with a negative effect of 25 and choosing randomly between spending 7,496,000 KZT and 3,254 minutes of transportation with a negative effect of 25 with probability p and spending 0 KZT and 0 minutes of transportation with a negative effect of 0 with probability (1-p)?

Answer: $p = U(x_1^*, x_2^0, x_3^*) =$ ______

TCS: 7 496 000 KZT
Time saving: 0 min
Heath effect: 25

~



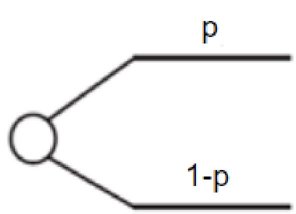
TCS: 7 496 000 KZT
Time saving: 3254 mins
Heath effect: 25

TCS: 0 KZT
Time saving: 0 min
Heath effect: 0

What probability (p) will cause you to remain indifferent between saving 0 KZT on transportation costs and 3254 minutes of transportation with a negative effect of 25 and choosing randomly between spending 7 496 000 KZT and 3,254 minutes of transportation with a negative effect of 25 with probability p and spending 0 KZT and 0 minutes of transportation with a negative effect of 0 with probability (1-p)?

Answer: $p = U(x_1^0, x_2^*, x_3^*) =$ ______

TCS: 0 KZT
Time saving: 3254 mins
Heath effect: 25



TCS: 7 496 000 KZT
Time saving: 3254 mins
Heath effect: 25

TCS: 0 KZT
Time saving: 0 min
Heath effect: 0

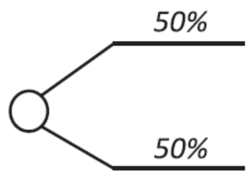
Appendix 8

Definition of the Utility Function for Attribute X_2 (Time Savings on Transportation) for Transporting Patients with Critical Cardiovascular Conditions (in Minutes)

In the tests below, please write in the blanks (____) the amount of time in hours, X_2, such that you are indifferent between the time savings on transporting the patient or choosing the transportation time randomly from the right side.

If in both cases: X_1^* =7496000 KZT, X_3^0 =1

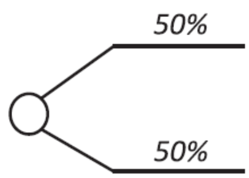
(1) $X_{0.50}$ = _________ mins ~
(your answer)



3254 min

0 min

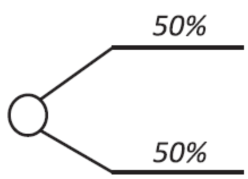
(2) $X_{0.25}$ = __________ mins ~
(your answer)



_____________ mins
put $X_{0.50}$ from (1)

0 min

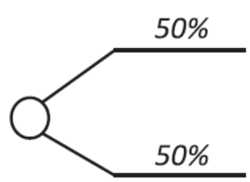
(3) $X_{0.75}$ = __________ mins ~
(your answer)



3254 mins

_____________ mins
put $X_{0.50}$ from (1)

(4) X_{check} = __________ mins ~
(your answer)



put $X_{0.75}$ from (3)
_____________ mins

put $X_{0.25}$ from (2)

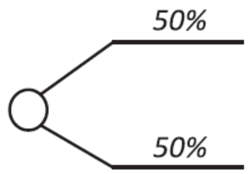
Appendix 9

Definition of the Utility Function for Attribute X_2 (Time Savings on Transportation) for Transporting Patients with Critical Cardiovascular Conditions (in Minutes)

In the tests below, please write in the blanks (____) the amount of time in hours, X_2, such that you are indifferent between the time savings on transporting the patient or choosing the transportation time randomly from the right side.

If in both cases X_1^0=0 tenge, X_3^*=25

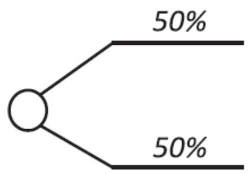
(1) $X_{0.50}$ = _________ mins ~
(your answer)



3254 min

0 min

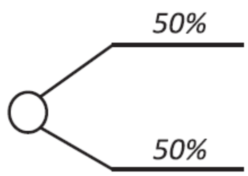
(2) $X_{0.25}$ = __________ mins ~
(your answer)



_____________ mins
put $X_{0.50}$ from (1)

0 min

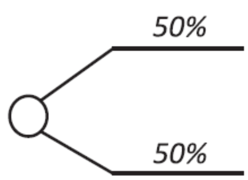
(3) $X_{0.75}$ = __________ mins ~
(your answer)



3254 mins

_____________ mins
put $X_{0.50}$ from (1)

(4) X_{check} = __________ mins ~
(your answer)



_____________ mins
put $X_{0.75}$ from (3)

_____________ mins
put $X_{0.25}$ from (2)

Appendix 10

Definition of the Utility Function for Attribute X_2 (Time Savings on Transportation) for Transporting Patients with Critical Cardiovascular Conditions (in Minutes)

In the tests below, please write in the blanks (____) the amount of time in hours, X_2, such that you are indifferent between the time savings on transporting the patient or choosing the transportation time randomly from the right side.

If in both cases X_1^0=0 tenge, X_3^0=1

(1) $X_{0.50}$ = _________ mins ~ 50% 3254 min; 50% 0 min
(your answer)

(2) $X_{0.25}$ = __________ mins ~ 50% _____________ mins put $X_{0.50}$ from (1); 50% 0 min
(your answer)

(3) $X_{0.75}$ = __________ mins ~ 50% 3254 mins; 50% _____________ mins put $X_{0.50}$ from (1
(your answer)

(4) X_{check} = __________ mins ~ 50% _____________ mins put $X_{0.75}$ from (3); 50% _____________ mins put $X_{0.25}$ from (2)
(your answer)

Appendix 11

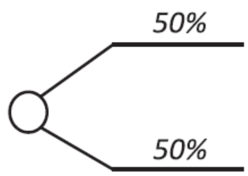
Definition of the Utility Function for Attribute X_3 (Impact of Transportation on Patient's Health) for Transporting Patients with Critical Cardiovascular Conditions (Assessed in Points According to the APACHE II Health Scoring System)

In the tests below, please write in the blanks (____) the number, X_3, such that you are indifferent between the patient's condition worsening by this number during transportation or by the number chosen randomly from the right side.

If in both cases: X_1^0=0 KZT, X_2^*=3254 min

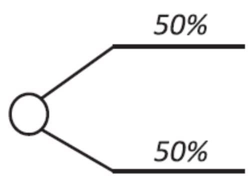
(1) $X_{0.50}$ = ____________ ~

(your answer)



25

1



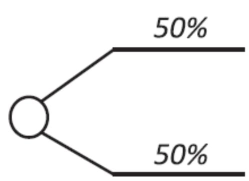
25

(2) $X_{0.75}$ = ____________ ~

(your answer)

____

put $X_{0.50}$ from (1)



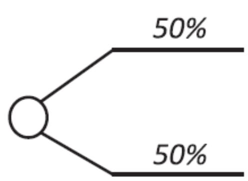
____

put $X_{0.50}$ from (1)

(3) $X_{0.25}$ = ____________ ~

(your answer)

1



____

put $X_{0.75}$ from (2)

(4) X_{check} = ____________ ~

(your answer)

____

put $X_{0.25}$ from (3)

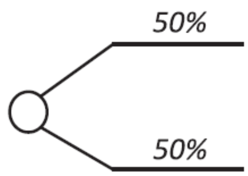
Appendix 12

Definition of the Utility Function for Attribute X_2 (Time Savings on Transportation) for Transporting Patients with Critical Cardiovascular Conditions (in Minutes)

In the tests below, please write in the blanks (____) the amount of time in hours, X_2, such that you are indifferent between the time savings on transporting the patient or choosing the transportation time randomly from the right side.

If in both cases X_1^*=7 496 000 KZT, X_3^*=25

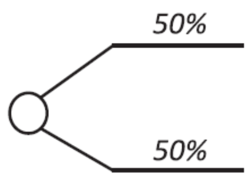
(1) $X_{0.50}$ = _________ mins ~
(your answer)



3254 min

0 min

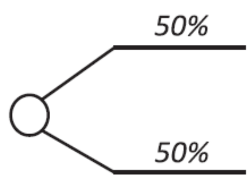
(2) $X_{0.25}$ = __________ mins ~
(your answer)



_____________ mins
put $X_{0.50}$ from (1)

0 min

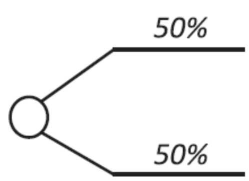
(3) $X_{0.75}$ = __________ mins ~
(your answer)



3254 mins

_____________ mins
put $X_{0.50}$ from (1)

(4) X_{check} = __________ mins ~
(your answer)



____________ mins
put $X_{0.75}$ from (3)

_____________ mins
put $X_{0.25}$ from (2)