Route Selection of Multimodal Transportation Considering Rain and Snow Conditions

Jianling Yang, Yuzhao Zhang, Muchen Ye, Luyuan Deng, and Yueqi Hu

Abstract—**The examination of intermodal transportation route selection, considering rain and snow conditions, provides valuable insights into intermodal transportation paths across diverse climatic scenarios. This paper integrates considerations of cargo value, cargo damage during transportation, as well as rain and snow conditions, drawing on existing research in multimodal transportation path optimization. A multi-objective model is formulated to achieve the dual objectives of minimizing transportation costs and shortening transportation time. This model is then converted into a single-objective framework using standardized weighting techniques. Leveraging the commercial solver Gurobi, the model is computed, resulting in optimal transportation paths and modes for various cost and time weight combinations. Aligned with the climatic characteristics of regions along the China-Kyrgyzstan-Uzbekistan Corridor, the optimal solutions under varying rain or snow conditions and cost or time distribution are determined. Furthermore, a comparative assessment of economic and temporal efficiency is conducted for the corridor before and after the establishment of the China-Kyrgyzstan-Uzbekistan Railroad. The findings demonstrate that following the railroad's inception, especially with a significant emphasis on cost weight, substantial cost and time savings in transportation are achieved. Remarkably, as rain and snow conditions intensify, there is a notable surge in the cost savings rate within the optimal solution. The standard gauge demonstrates an enhancement from a savings rate of 30.6% under entirely dry conditions to 45.7% under fully icy conditions, while the broad gauge experiences an increase from 8.5% to 47.8%. However, the influence of rain and snow conditions on the time savings rate is comparatively modest.**

Index Terms—**Rain and snow conditions, the cargo damage rate, different districts, coefficient of friction**

I. Introduction

In the "14th Five-Year Transportation Plan" issued by the State Council of China, it is emphasized that there is active promotion of the development of multimodal goods transportation and encouragement for railway and road transportation enterprises to become operators in multimodal transportation. This highlights the significance of multimodal transportation development. The continuous advancement of the "Belt and Road" initiative has greatly facilitated economic trade between Asia and Europe. The adjustment of related policies and the construction of intermodal transportation in the China- Kyrgyzstan- Uzbekistan Corridor will further enhance the connectivity of the "Belt and Road." During winter cargo transportation in the region of the China- Kyrgyzstan- Uzbekistan Corridor, the impact of rain and snow is inevitable. This alteration influences the selection of transportation routes. Therefore, the study of intermodal transportation considering rain and snow conditions is indispensable for intermodal carriers.

The choice of intermodal routes is influenced by a myriad of factors, including but not limited to container characteristics, seasonal demand fluctuations, time constraints, customer satisfaction metrics, logistical capacity limitations, exposure to transportation risks, uncertain travel speeds, hub congestion dynamics, and the diverse range of carbon reduction policies. The differentiation arising from various container types is comprehensively addressed in [1]. Notably, it incorporates container utilization costs within the overarching objective function. Dealing with uncertain demand, [2][3] also contribute by considering these aspects in their work. Moreover, [4][5] introduces fuzzy demand and fuzzy transportation time represented through triangular fuzzy numbers.

The complexities of hybrid temporal parameters are effectively modeled in the scenario-based robust optimization framework developed by [6][7][8]. In parallel, [9] introduces the minimization of shipper dissatisfaction as a pivotal objective. Anchored in service capacity and temporal uncertainty, [10] presents an integer planning model. [11] constructs a reliability-centric optimization model, encompassing demand and environmental uncertainties. [12] formulates a two-tier optimal scheduling model that simultaneously optimizes time efficiency and minimizes variance in emergency supply distribution. The uncertainty of transportation speeds is examined by [13][14][15]. Hub congestion and its impact are analyzed by [16] using queueing theory. Extending the discourse, the ramifications of diverse carbon reduction policies on multimodal transportation path selection are explored by [17][18][19]. However, currently, there remains a scarcity of studies addressing the incorporation of rain and snow conditions in multimodal transport route selection.

Prior studies such as [20][21][22] have focused on intermodal transportation scenarios involving high-value

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goods or laptop computers as transported commodities. These studies aimed to develop optimal path selection models for minimizing overall costs along the Central-European corridor. They took into account aspects such as goods depreciation during transit and prudent fund allocation. However, these investigations did not explicitly consider cargo damage characteristics during transportation and transshipment processes.

Moreover, [23] introduced the concept of service quality commitment, integrating cargo integrity as a pivotal factor affecting quality loss costs. In a similar vein, [24] developed an optimization model for a railroad cold chain logistics network. This model aimed to minimize overall transportation costs, mitigate carbon emissions, and lower cargo damage rates. However, the study did not primarily delve into the specific variations in cargo damage rates for different types of goods under diverse rain and snow road conditions.

Within the realm of international multimodal transportation, substantial literature has been dedicated to the examination of major corridors in Central Europe. However, comparatively fewer studies have explored multimodal transportation pathways within the China- Kyrgyzstan-Uzbekistan Corridor. For instance, focusing on the transport network connecting Changsha and Berlin, [25] investigated the intricate relationship between transportation objectives- comprising cost, time, integrated energy consumption, and transportation risk- across corridors such as the Asia-Europe Continental Bridge and traditional maritime transportation. Similarly, [26] employed a genetic algorithm to compute optimal paths from Nanjing to Berlin, catering to distinct carrier demands in terms of cost, time, and carbon emissions. Meanwhile, [27] examined the selection of export routes from Heilongjiang to Russia, considering user demands related to carbon emissions, freight rates, and time constraints. Noteworthy is [28], which employed mathematical analysis to validate the feasibility of the intermodal route "Urumqi- Kashgar- Irkeshtan- Osh- Andijan- Tashkent," underscoring the efficacy of this method in route verification. Furthermore, research endeavors have identified optimal intermodal routes within the China-Kyrgyzstan- Uzbekistan Corridor, optimizing for minimized temporal requirements and streamlined transportation costs. Nonetheless, the question of whether these optimal routes and transportation modes would undergo alteration under differing conditions has yet to be comprehensively addressed in the existing literature.

With that said, this paper centers its attention on aspects such as goods valuation, cargo damage during transportation, and climatic characteristics. Concurrently, it develops a path selection model with the dual objective of minimizing the total cost, encompassing transportation expenses, container rental, and cargo damage costs, while also seeking to minimize the overall time. Within the framework of this model, the paper serves as an initial reference for potential transportation arrangements under rainy and snowy conditions within the China-Kyrgyzstan-Uzbekistan Corridor. Furthermore, it investigates the impact of the operational China-Kyrgyzstan-Uzbekistan Railroad on transportation costs and time following its implementation.

II. Analysis of the Impact of Rain and Snow on Transportation

The presence of rain and snow during the transportation of goods can impact variables such as speed, unit cost, and cargo damage rate.

A. Changes in the coefficient of friction

The presence of rain and snow can alter the coefficient of friction on path surfaces, resulting in significant differences between dry, rainy, snowy, and icy conditions. Furthermore, these changes in friction coefficients can impact the safe average transportation speed. As a result, road surfaces in transportation are categorized into four types: dry, rainy, snowy, and icy.

In the context of transportation, a truck or train is treated as a uniform motion of a mass point. During the deceleration process, it is assumed to undergo uniform deceleration motion. In this context, Newtonian mechanics provide the following formula.

$$\mu mg = ma \tag{1}$$

$$v_1^2 - v_0^2 = 2as \tag{2}$$

$$v_1^2 - v_0^2 = 2\mu gs \tag{3}$$

Equation (3) presents a synthesis of (1) and (2). In the context of deceleration, the speed transitions from v_1 to v_0. For the purpose of calculation, v_1 is considered to be 0, and a consistent value is assigned to the deceleration distance s for the identical mode of transportation. Consequently, the safe speed v_1 during uniform motion can be computed for each respective friction coefficient μ.

B. Changes in unit cost and cargo damage rates

Rain and snow have a limited impact on rail transportation, while road transportation is significantly affected. The unit transportation price and cargo loss ratio experience increases for rainy, snowy, and icy surfaces when compared to dry surfaces. The unit price and loss ratio for other surface conditions are derived by multiplying the unit price and loss ratio for dry surfaces by the corresponding percentage increase for each surface.

Designating (p_1, p_2, p_3, p_4) and (d_1, d_2, d_3, d_4) as the unit tariffs and cargo damage rates for domestic highways, domestic railroads, foreign highways, and foreign railroads, respectively, under dry pavement conditions, (rp_1, rp_2, rp_3) and (d_1, d_2, d_3, d_4) represent the percentage increase in unit fare and cargo loss rate for rainy, snowy, and icy surfaces, respectively. The unit tariffs and cargo damage rates for the four modes of transportation under the four surface conditions are as follows:

$$\begin{pmatrix} p_1 & p_1(1+rp_1) & p_1(1+rp_2) & p_1(1+rp_3) \\ p_2 & p_2 & p_2 & p_2 \\ p_3 & p_3(1+rp_1) & p_3(1+rp_2) & p_3(1+rp_3) \\ p_4 & p_4 & p_4 & p_4 \end{pmatrix} \tag{4}$$

$$\begin{pmatrix} d_1 & d_1(1+rd_1) & d_1(1+rd_2) & d_1(1+rd_3) \\ d_2 & d_2 & d_2 & d_2 \\ d_3 & d_3(1+rd_1) & d_3(1+rd_2) & d_3(1+rd_3) \\ d_4 & d_4 & d_4 & d_4 \end{pmatrix} \tag{5}$$

C. Path area division

The classification of a path as dry, rainy, snowy, or icy is contingent upon both the prevailing season and the specific geographical region. By scrutinizing the geographical attributes and rain and snow conditions associated with each node and route within the transportation network, the entire network is segmented into distinct zones.

III. Multiobjective Model Construction

A. Description of the problem

A shipment of containers is scheduled to be transported by an intermodal operator from a domestic origin 1 to a foreign destination 12, as shown in Fig.1. The domestic nodes (2,3,...), customs clearance ports (5,6), and foreign nodes (7,8,...) may pass through on the way. Two modes of transportation are chosen, road and rail, both domestic and foreign. The transportation network is divided into different districts based on the rainfall and snowfall characteristics of each node segment in the network. In addition, dryness, rain, snow, and ice will occur in each region. There exist different unit transportation costs c_{ij}^{kf}, between adjacent nodes i and j, in road conditions f, using transportation modes k. At the same time, there are different friction coefficients u_{ij}^{kf}. There exist different cargo damage rates g_i^{dk} and a_{ij}^{df} in different transportation nodes and between nodes. The coefficient of friction of the surface is affected by the degree of snow and ice accumulation on the road surface. The cargo damage rate is also affected by the facilities and equipment in different sections and nodes. Therefore, the friction coefficients and the damage rates during transportation and switching are set to follow the corresponding normal distribution. In addition, the containers used in the transportation process incur rental costs. The aim is to find the optimal transportation solution under different conditions.

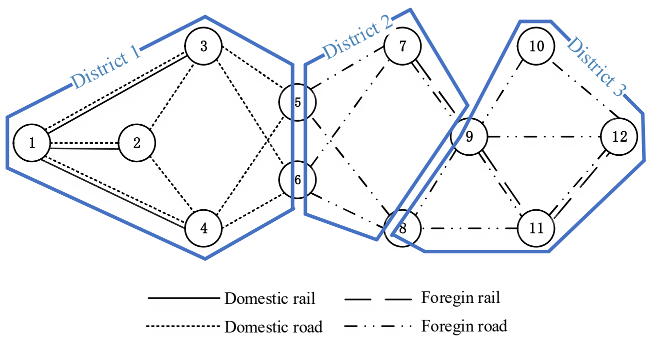

Fig.1. International multimodal transportation network diagram

In the context outlined in Fig.1, a shipment of containers is slated for transportation by an intermodal operator. This journey commences from a domestic origin, denoted as 1, and concludes at a foreign destination, signified as 12. Throughout this course, the route may traverse domestic nodes (2, 3, ...), customs clearance ports (5, 6), and foreign nodes (7, 8, ...). To facilitate this movement, two modes of transportation are elected: road and rail, encompassing both domestic and foreign segments. The transportation network is meticulously partitioned into distinct zones, predicated on the rainfall and snowfall profiles intrinsic to each node segment within the network. Consequently, within these zones, varying degrees of dry, rainy, snowy, and icy conditions prevail. Notably, diverse unit transportation costs c_{ij}^{kf} exist between adjacent nodes i and j for differing road conditions f and transportation modes k. Simultaneously, unique friction coefficients u_{ij}^{kf} are pertinent to these contexts. Diverse cargo damage rates g_i^{dk} and a_{ij}^{df} manifest across various transportation nodes and inter-nodal sections. The coefficient of friction for road surfaces is notably influenced by the extent of snow and ice accumulation. Furthermore, cargo damage rates are influenced by the facilities and equipment operational within distinct sections and nodes. Given these considerations, both friction coefficients and damage rates during transportation and transitions adhere to corresponding normal distributions. It is pertinent to note that container usage during transportation incurs rental costs. The overarching objective of this task is to determine the optimal transportation strategy under different conditions.

TABLE I
PARAMETER LISTS

Symbolic		Explanations
Sets	N	Set of nodes
	D	Set of transportation modes, including domestic rail, domestic road, foreign rail and foreign road.
	F	Set of path conditions, including dry, rainy, snowy, and icy surfaces
Parameters	q	Volume of freight
	a_{ij}^{kf}	Cargo damage rate for transportation modes k under conditions f between nodes i and j
	g_i^{dk}	Cargo damage rate at a node i from transportation mode d to k
	c^{kf}	Unit transportation cost of transport mode d in road condition f
	e_i^{dk}	Unit conversion cost from transportation mode d to transportation mode k at node i
	p	The total value of goods
	u_{ij}^{kf}	Friction coefficients for road conditions encountered using transportation mode k between nodes i and j
	t_i^{dk}	Time to switch from transportation mode d to node i
	s_k	Distance from average safe transport speed automatically reduced to 0 using transport mode k
	θ	Unit rental costs
	l_{ij}^k	Transportation distance between nodes i, j for transportation mode k
	g	gravitational constant
	α	Weighting of costs
	β	Weighting of time
Decision variable	x_{ij}^k	Whether the mode of transportation between nodes i, j is k, if so take 1, else take 0
	y_i^{dk}	On whether the node i is converted from transportation mode d to k, if yes take 1, else take 0

B. Model Assumptions

(1) During the transportation process, goods maintain an indivisible status. Consequently, each pair of nodes permits only a single mode of transportation and a sole transportation path.

(2) Within this framework, goods undergo direct conveyance to the subsequent destination post-loading and unloading without being warehoused at transit stations. Importantly, the expenses associated with loading and unloading operations are directly integrated into the transit cost, and the duration of loading and unloading is seamlessly incorporated into the overall transit time.

(3) The transition in transportation mode is confined exclusively to transit stations within transportation nodes. Moreover, any given transshipment station is involved in a maximum of one instance of transportation mode alteration.

C. Definition of parameters

The parameters used in this model are detailed in Table I.

D. Objective function

The transit transportation cost is determined by aggregating the costs associated with transportation across all chosen segments. The cost for each segment is computed as the product of the unit transportation price, the distance of transport, and the volume of freight being conveyed. On the other hand, transshipment costs entail the expenses incurred in transitioning the shipment from one mode of transportation to another at the nodes situated along the intermodal pathway. For a singular node within the transit process, the transit cost is the outcome of multiplying the freight volume with the unit transit cost.

$$C_1 = \sum_{i\in N, j\in N} \sum_{k\in D, f\in F} qc^{kf} l_{ij}^k x_{ij}^k + \sum_{i\in N, j\in N} \sum_{d,k\in D} qe_i^{dk} y_i^{dk} \quad (6)$$

The cost associated with container rental during transportation is calculated as the product of the transportation time and the per-unit rental cost of the container.

$$C_2 = \Big(\sum_{i\in N, j\in N} \sum_{k\in D, f\in F} \frac{l_{ij}^k}{\sqrt{2u_{ij}^{kf} gs_k}} x_{ij}^k + \sum_{i\in N} \sum_{d,k\in D} qt_i^{dk} y_i^{dk}\Big)\theta \quad (7)$$

The expense attributed to goods damage during transportation and transshipment is determined by multiplying the value of the goods with their respective damage rate.

$$C_3 = \sum_{i\in N, j\in N} \sum_{k\in D, f\in F} a_{ij}^{kf} px_{ij}^k + \sum_{i\in N, j\in N} \sum_{d,k\in D} g_i^{dk} py_i^{dk} \quad (8)$$

The total cost consists of transportation costs, container rental costs, and cargo damage costs.

$$\min C = C_1 + C_2 + C_3 \quad (9)$$

The time spent in transportation can be dissected into two main components: transit time and switch-over time. Transit time is determined by dividing the distance covered by the average speed, which is contingent on the coefficient of friction and the deceleration distance in the kinematic equation. Meanwhile, switch-over time is calculated as the product of the per-unit switch-over time and the volume of freight being transported.

$$\min T = \sum_{i\in N, j\in N} \sum_{k\in D, f\in F} \frac{l_{ij}^k}{\sqrt{2u_{ij}^{kf} gs_k}} x_{ij}^k + \sum_{i\in N} \sum_{d,k\in D} qt_i^{dk} y_i^{dk} \quad (10)$$

The principal objective of this paper is to discover the optimal transportation solution characterized by the lowest cost and shortest time.

E. Constraints

$$\sum_{d\in D} x_{ij}^d \le 1, \forall i, j \in N \quad (11)$$

$$\sum_{d,k\in D} y_i^{dk} \le 1, \forall i \in N \quad (12)$$

$$\sum_{k\in D} x_{ij}^k = \sum_{d\in D} x_{jm}^d, \forall i, j, m \in N \quad (13)$$

$$\sum_{d\in D} x_{ij}^d x_{jm}^k = \sum_{d,k\in D} y_j^{dk}, \forall i, j, m \in N, h \in D, d \ne k \quad (14)$$

$$\sum_{d\in D} x_{Oj}^d = 1, \forall O, j \in N \quad (15)$$

$$\sum_{d\in D} x_{iD}^d = 1, \forall i, D \in N \quad (16)$$

$$x_{ij}^d \in \{0,1\}, \forall i, j \in N, d \in D \quad (17)$$

$$y_i^{dk} \in \{0,1\}, \forall i \in N, d, k \in D \quad (18)$$

Constraint (11) signifies that commodities can exclusively be designated for transportation through a single mode between two nodes. Constraint (12) underscores that at any given node, goods can be switched at most once. Constraints (13) and (14) serve the purpose of upholding the continuity of the transportation pathways. Constraints (15) and (16) explicitly dictate that both the starting point and the endpoint must be incorporated within the chosen route. Moreover, Constraints (17) and (18) encompass 0-1 constraints which serve to impose limitations on the decision variables.

F. Methods of solving

The aforementioned model constitutes a bi-objective formulation, which is subsequently transformed into a single-objective framework by means of normalized weighted aggregation of transportation costs and time, accomplished through the following two steps:

(1) The normalization process involves the application of the maximum-minimum normalization method to costs and time. Given that cost and time are inherently distinct measures that lack direct comparability for direct weighting and summation, standardization is requisite. In the initial phase, the maximum cost $\max\_\cos t$ and minimum time $\min\_time$ are acquired by assigning a time weight of 1 and a freight weight of 0. Conversely, the minimum cost $\min\_\cos t$ and maximum time $\max\_time$ are computed by assigning a freight weight of 1 and a time weight of 0. The normalized objective function is delineated as follows:

$$obj = \min\Big(\alpha \frac{C - \min\_\cos t}{\max\_\cos t - \min\_\cos t} + \beta \frac{T - \min\_time}{\max\_time - \min\_time}\Big) \quad (19)$$

$$\alpha + \beta = 1 \quad (20)$$

$$\alpha, \beta \ge 0 \quad (21)$$

The variables α and β represent the weights assigned to transportation cost and time, respectively.

(2) After determining the optimal outcome, a back-standardization procedure is employed to revert the target value to its actual transportation cost and time values.

The choice of weights can be tailored according to the distinct preferences of multimodal carriers about transportation cost and time. The converted model then assumes the form of a single-objective linear optimization

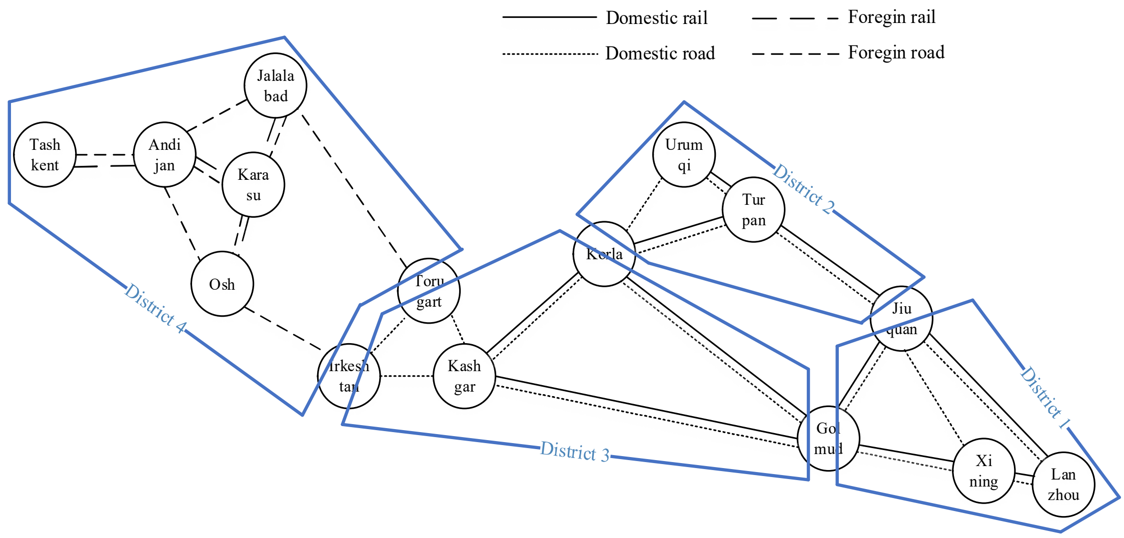

Fig.2. Case Transportation Network

framework. In contrast to intelligent optimization algorithms, the Gurobi solver offers superior efficiency and precision when addressing linear optimization problems. Therefore, in this study, we leverage the Python language to invoke the Gurobi interface for resolving the formulated model.

IV. Case Analysis

A. Case description

TABLE II
DISTANCE BETWEEN NODES (KM)

Nodes	Road	Rail	Nodes	Road	Rail
Lanzhou- Xining	246	216	Korla-Kashgar	1036	989
Lanzhou-Jiuquan	710	620	Kashgar-Irkeshtan	232	
Xining-Jiuquan	547		Kashgar- Torugart	166	
Xining-Golmud	790	814	Torugart-Jalalabad	522	
Jiuquan-Tulufan	1020	1001	Irkeshtan-Osh	255	
Jiuquan - Golmud	966	1026	Jalalabad-Andijan	84	
Golmud-Korla	1211	1213	Jalalabad-Karasu	120	58
Golmud-Kashgar	2200	2525	Karasu-Andijan	68	94
Turpan-Urumqi	204	154	Osh-Karasu	24	52
Turpan- Korla	369	457	Osh-Andijan	81	
Urumqi- Korla	482		Andijan-Tashkent	350	569

TABLE III
CASES FOR RAIN AND SNOW CONDITIONS IN DIFFERENT DISTRICTS

Case	District 1	District 2	District 3	District 4
1	Rain	Dry	Dry	Dry
2	Dry	Rain	Dry	Dry
3	Rain	Rain	Dry	Dry
4	Rain	Rain	Dry	Rain
5	Rain	Rain	Rain	Rain
6	Dry	Snow	Dry	Dry
7	Dry	Snow	Snow	Dry
8	Dry	Snow	Snow	Snow
9	Snow	Snow	Snow	Snow
10	Snow	Icy	Snow	Snow
11	Snow	Icy	Icy	Snow
12	Snow	Icy	Icy	Icy
13	Icy	Icy	Icy	Icy

Let's consider the example of transporting ten 40-foot containers from Lanzhou, China, to Tashkent, the capital of Uzbekistan. The aggregate value of the cargo stands at 5 million yuan. The gravitational constant is measured at 9.8, while the container rental cost is set at 120 yuan per day. According to the research data provided by the relevant departments and network information, the unit transportation prices for domestic highways, domestic railroads, foreign highways, and foreign railroads on dry road surfaces are assigned as follows: (8, 5, 13, 7). Furthermore, the mean cargo loss rates for highways and railroads are identified as 0.0001 and 0.001, respectively. An augmented ratio of unit transportation price and cargo loss rate for rainy, snowy, and icy road conditions is established at (0.2, 0.3, 0.4). Notably, the standard deviation of cargo loss rates is quantified at 0.0001. Associated with the four pavement conditions, the average friction coefficients are presented as (0.6, 0.4, 0.28, 0.18) for road, and (0.16, 0.14, 0.12, 0.08) for railroad. These values are accompanied by standard deviations of 0.01 and 0.001, respectively. The transportation network is graphically depicted in Fig.2, and Table II comprehensively showcases the transportation distances between nodes. These distances have been sourced from Gaode Maps, Google Maps, and OpenRailwayMap. Moving on to Table IV, the cost and time of each unit of mode transition is presented. Guided by the distinct weather characteristics observable across each region within the transportation network, rain and snow conditions within various districts are categorized into 13 distinct cases as detailed in Table III.

TABLE IV
COST PER UNIT CHANGEOVER (YUAN)/ UNIT CHANGEOVER TIME (H)

	Domestic road	Domestic rail	Foreign road	Foreign rail
Domestic road	0/0	8/4	6/3	8/4
Domestic rail	8/4	0/0	8/4	10/6
Foreign road	6/3	8/4	0/0	8/4
Foreign rail	8/4	10/6	8/4	0/0

B. Analysis of Results

In the absence of considering rain and snow conditions, Table V demonstrates the shifts in optimal routes and transportation modes under varying cost weighting. Notably, the alterations in transportation paths are relatively minimal, whereas transportation modes exhibit more pronounced variations. Specifically, when the cost weight attains a value of 0.8 or greater, the preference leans towards rail transportation characterized by a lower unit freight cost. However, for the Kashgar-Osh section where rail infrastructure is absent, road transportation is favored. As the cost weight gradually diminishes and the time weight proportionately ascends, a growing proportion of road transportation modes are favored. Upon reaching a cost weight of 0.7, the optimal transportation path is devoid of the Karasu node. Subsequently, when the cost weight dips below 0.3, the transportation mode transitions entirely to road transportation. The trajectory of transportation cost and time in relation to the cost weight is illustrated in Fig.3. Evidently, with an increasing cost weight, transportation cost progressively diminishes, while time correspondingly increases.

TABLE V
EFFECT OF COST WEIGHT ON TRANSPORTATION PATHS

Cost weight	Transportation route	Transportation mode
0.8,0.9,1	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Karasu- Andijan-Tashkent	Rail– rail- rail- rail- road- road- rail- rail- rail
0.4,0.5,0.6,0.7	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Andijan-Tashkent	rail- rail- rail- rail- road- road- road- road
0,0.1,0.2,0.3	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Andijan-Tashkent	road- road- road- road- road- road- road- road

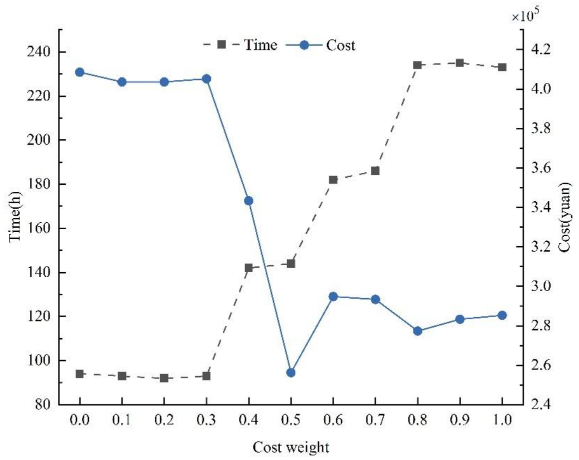

Fig.3. Changes in transportation costs and time with cost weights

C. *Effect of rain and snow conditions on transportation paths*

The effects of the weights of cost and time on the optimal transportation path and mode of transportation when rain and snow conditions are considered are shown in Tables VI and Table VII. There are a total of four schemes A, B, C, and D in Table VI.

TABLE VI
OPTIMAL PATH SCHEMES CONSIDERING RAIN AND SNOW CONDITIONS

Scheme	Transportation route	Transportation mode
A	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Karasu- Andijan-Tashkent	rail- rail- rail- rail- road- road- rail- rail- rail
B	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Andijan-Tashkent	rail- rail- rail- rail- road- road- road- road
C	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Andijan-Tashkent	road- road- road- road- road- road- road- road
D	Lanzhou- Xining- Golmud- Kashgar- Irkeshtan- Osh- Andijan-Tashkent	road- road- road- road- road- road- road

As evident from Table VII, irrespective of the scenario, a consistent trend emerges as the cost weights vary from 0 to 1. This trend manifests as a gradual transition in transportation mode preference from predominantly road-based options towards a pronounced inclusion of railroads. Rain, snow, ice, and slippery road conditions introduce escalated transportation costs, curtailed transit speeds, and heightened cargo damage rates. Consequently, the optimal path endeavors to circumvent these adverse conditions. The responsiveness of optimal transportation path and mode alterations to cost weight is notably influenced by rain and snow conditions. For instance, in cases 8, 9, and 10, the optimal path shifts to the road-rail multimodal transportation Scheme A at a cost weight of 0.5. Conversely, in cases 2, 3, 6, and 7, this transition to Scheme A is not until when the cost weight reaches 0.8.

TABLE VII
OPTIMAL SCHEMES CONSIDERING RAIN AND SNOW CONDITIONS WITH THE DIFFERENT CASES AND COST WEIGHT

Cost weight / Case	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	C	C	C	B	B	B	B	A	A	A	A
2	D	D	D	D	B	B	B	B	A	A	A
3	D	D	D	B	B	B	B	B	A	A	A
4	D	D	D	B	B	B	A	A	A	A	A
5	C	C	C	B	B	B	B	A	A	A	A
6	D	D	D	D	B	B	B	B	A	A	A
7	D	D	D	D	B	B	B	B	A	A	A
8	D	D	D	B	B	A	A	A	A	A	A
9	C	C	B	B	B	A	A	A	A	A	A
10	D	D	D	B	B	A	A	A	A	A	A
11	C	C	B	B	B	A	A	A	A	A	A
12	C	C	B	B	B	A	A	A	A	A	A
13	C	C	B	B	B	A	A	A	A	A	A

The selection of the most suitable transportation scheme is intrinsically tied to both rain and snow conditions and the weight assigned to costs. Consequently, the optimal transportation strategy should be tailored by specific scenarios and the underlying demands for cost and time considerations.

The variations in total transportation costs and time across distinct cases and differing weights of cost or time are visually represented in Fig.4 and Fig.5. Within the same case, as the cost weight escalates (while the time weight diminishes), the overall transportation cost undergoes a decrease, while the time duration experiences an increase.

The sequence of cases 1 to 13 mirrors a progression from dry to rainy, snowy, and icy conditions as delineated in Table II. These cases span from single instances of rainy or snowy districts to multiple such districts. Notably, an augmented presence of rainy and snowy districts magnifies their impact on transportation costs and time. The cumulative effect is reflected in a consistent increase in both total transportation cost and time from case 1 to case 13. When cost weights are relatively modest, the optimal path's cost exhibits greater variability across cases. Conversely, with higher cost weights, the disparity in optimal path cost across cases diminishes, and the time variation follows a parallel trend. This observation stems from the fact that objectives accorded greater weights exert a more substantial influence on the cumulative objective as compared to objectives with lesser weights.

In scenarios where stringent time requirements are at play, road transportation is preferred by carriers to the fullest extent possible. However, as an increasing number of districts become characterized by snowy or icy conditions, the speed of road transportation diminishes and costs rise. Consequently, while road transportation offers time savings, the concurrent cost escalation becomes more pronounced.

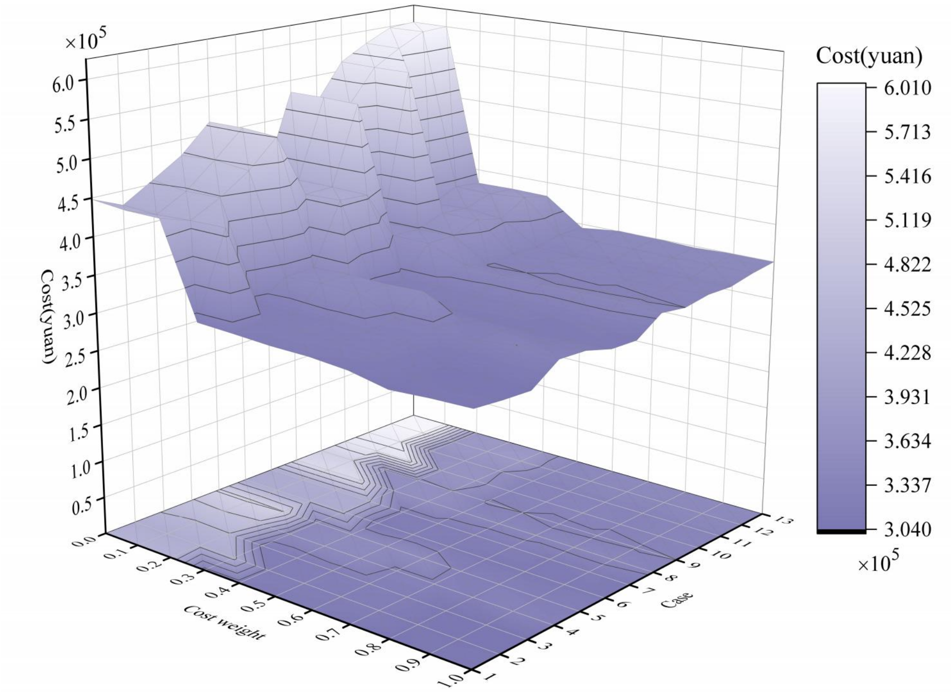

Fig.4. Changes in transportation costs with different cases and cost weights

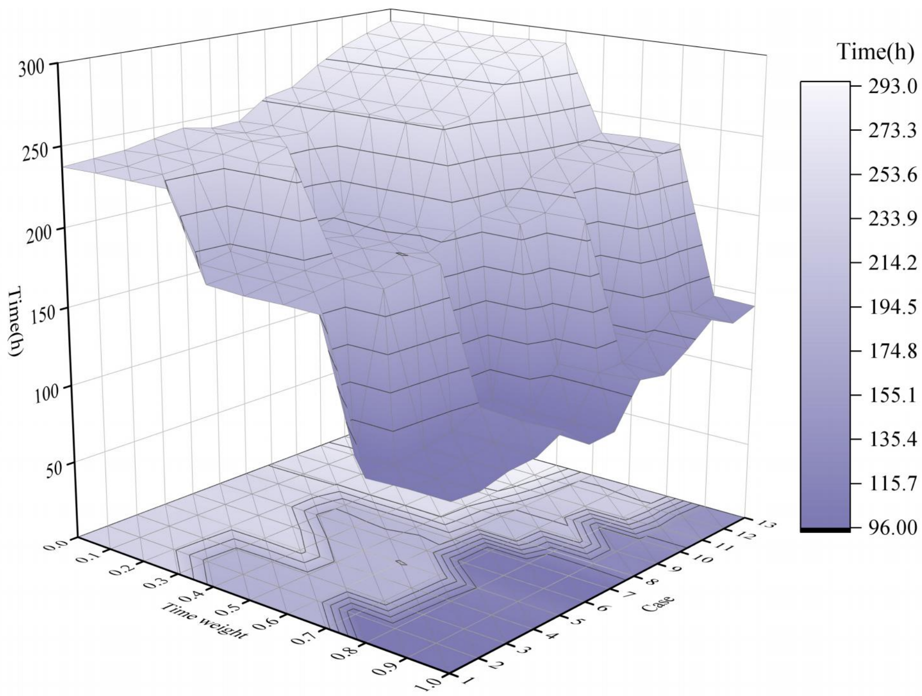

Fig.5. Changes in transportation time with different cases and cost weights

D. Influence of cargo Value on the transportation route

The rate of cargo damage in rail transportation surpasses that in road transportation. However, when the cargo value is lower, its impact on costs remains negligible. Yet, as the value of goods escalates, the cost linked to cargo damage progressively rises, resulting in significant cost fluctuations. The effect of cargo value on the optimal transportation strategy is depicted in Table VIII for case 9 (entire snowpack) at a cost weight of 0.5. It is evident that, with increasing cargo value, the transportation mode gradually evolves. Initially, rail-road multimodal transport involves a higher proportion of railroads, subsequently transitioning towards a more balanced rail-road multimodal mix, and ultimately favoring total road transport.

TABLE VIII
EFFECT OF CARGO VALUE ON THE OPTIMAL TRANSPORTATION SCHEME

Value of a container of cargo(yuan)	Transportation route	Transportation mode
500000	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Karasu- Andijan-Tashkent	rail- rail- rail- rail- road- road- rail- rail- rail
1000000	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Andijan-Tashkent	rail- rail- rail- rail- road- road- road- road
1500000	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Andijan-Tashkent	rail- rail- road- road- road- road- road- road
2000000	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Andijan-Tashkent	road- road- road- road- road- road- road- road

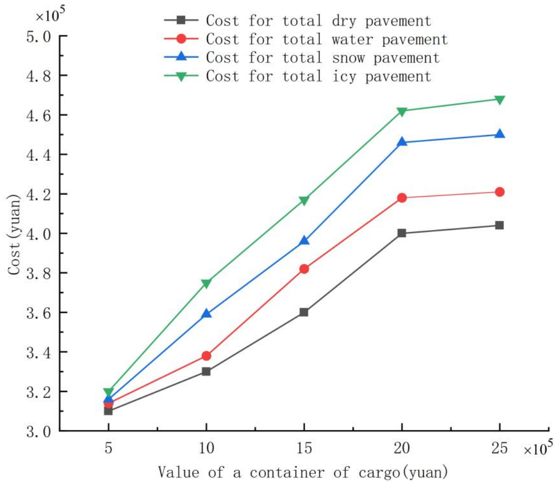

Fig.6. Changes in transportation costs with the value of goods

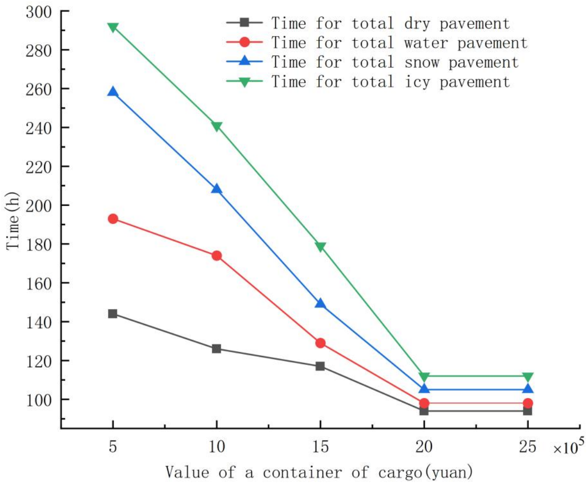

Fig.7. Changes in transportation time with the value of goods

When the cost weights are set to 0.5, the variations in transportation cost under conditions of complete dryness, rain, snow, and icy terrains concerning cargo value are depicted in Figure 6. Simultaneously, the adjustments in transportation time are illustrated in Figure 7. Clearly, with an increase in cargo value, the transportation cost within the optimal transport solution exhibits an upward trend, accompanied by a simultaneous reduction in the required time. It is noteworthy that the trends in cost variations and time fluctuations corresponding to dryness, rain, snow, and ice progressively intensify in sequence. This observed phenomenon can be attributed to the heightened susceptibility of the transportation scheme to variations as cargo values fluctuate, particularly under non-dry conditions. Consequently, the degree of variation in transportation mode is directly correlated with the magnitude of changes observed in both cost and time.

E. Impact of the commissioning of China- Kyrgyzstan-Uzbekistan railroad

In the presence of the railroad line connecting Kashgar and Jalalabad via the Irkeshtan crossing, which forms a part of the China-Kyrgyzstan-Uzbekistan Railroad, two distinct scenarios emerge. If the standard gauge is adopted, the mode of transportation is transitioned to Jalalabad. Alternatively, with the construction of the broad gauge, the mode conversion occurs at Kashgar.

TABLE IX
THE OPTIMAL ROUTE SCHEME OF CHINA-KYRGYZSTAN-UZBEKISTAN RAILWAY AFTER PUTTING INTO OPERATION

Scheme	Transportation route	Transportation mode
E	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Irkeshtan- Osh- Andijan-Tashkent	road- road- road- road- road- road- road- road
F	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Jalalabad- Andijan-Tashkent	rail- rail- rail- rail- rail(standard gauge)- road- road
G	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar(transformation station)- Jalalabad- Karasu- ndijan-Tashkent	rail- rail- rail- rail(standard gauge)- rail(broad gauge)- rail- rail-rail
H	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Jalalabad(transformation station)- Karasu- Andijan-Tashkent	rail- rail- rail- rail- rail(standard gauge)- rail(broad gauge)- rail-rail
I	Lanzhou- Jiuquan- Tulufan- Korla- Kashgar- Jalalabad- Andijan-Tashkent	rail- rail- rail- rail- rail(standard gauge)- road- rail

The optimal transportation schemes for the China-Kyrgyzstan- Uzbekistan Railway after its commissioning are presented in Tables IX and X. In Scheme G, the gauge at the Kashgar node changes from standard to broad, necessitating gauge conversion at that point. Likewise, Scheme H undergoes a gauge change at the Jalalabad node, requiring gauge conversion at that location as well.

Regardless of whether the China- Kyrgyzstan- Uzbekistan Railway adopts a broad or standard gauge after its commencement of operations, certain patterns emerge. When the cost weight is low, the optimal route is consistently identified as Scheme E, involving full- road transportation. However, as the cost weight increases, a shift towards combined rail- road transportation methods is observed. Eventually, this evolves into a scenario where rail transportation plays a more prominent role, either in a mixed rail-road transport or entirely rail transport. The optimal solution, characterized by a lower cost weight, is inclined to

TABLE X
THE OPTIMAL SOLUTION FOR DIFFERENT GAUGES UNDER RAIN AND SNOW CONDITIONS AFTER THE CHINA-KYRGYZSTAN-UZBEKISTAN RAILWAY IS PUT INTO OPERATION

Type of gauge that has been put into production	Cost weight / overall surface weather conditions	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Standard gauge	Dry	E	E	E	F	F	F	F	F	F	F	F
	Water	E	E	E	F	F	F	F	F	F	F	F
	Snow	E	E	F	F	F	F	F	H	H	H	I
	Icy	E	E	F	F	F	F	H	H	H	H	H
broad gauge	Dry	E	E	E	E	G	G	G	G	G	G	G
	Water	E	E	F	F	F	H	H	H	H	H	H
	Snow	E	E	E	E	G	G	G	G	G	G	G
	Icy	E	E	E	G	G	G	G	G	G	G	G

shift towards full-rail transportation. This transition follows the sequence of surfaces affected by rainfall, snow accumulation, and ice formation.

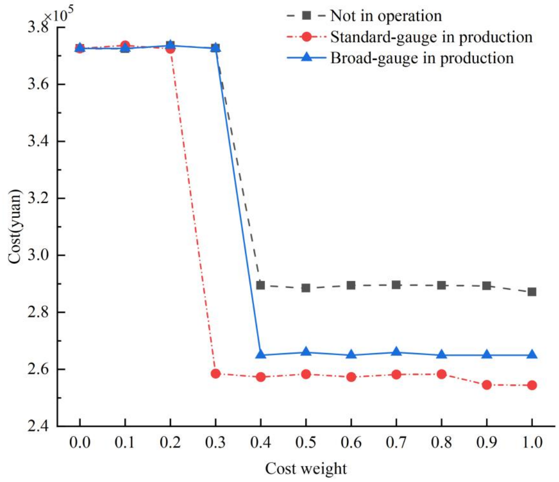

Fig.8. Changes in the minimum transportation cost with cost weight before and after the operation of the China-Kyrgyzstan-Uzbekistan Railroad on a comprehensive dry pavement

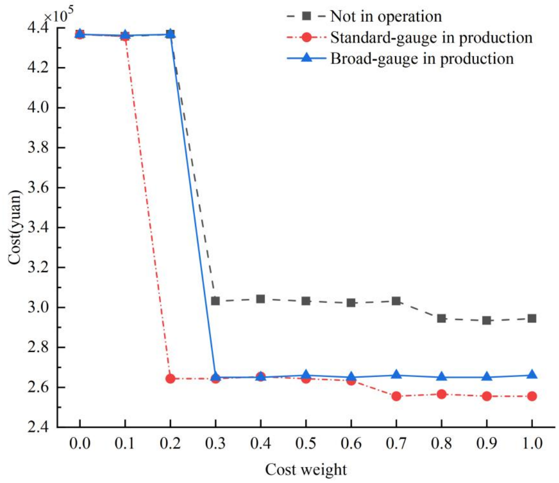

Fig.9. Changes in the minimum transportation cost with cost weight before and after the operation of the China-Kyrgyzstan-Uzbekistan Railroad on a comprehensive water pavement

The optimal solution varies significantly depending on whether a broad or standard gauge is adopted for the Kashgar-Jalalabad segment, even under the same cost weight. Specifically, on a comprehensive water pavement, choosing the standard gauge results in a shift to a mixed rail-road transportation solution (Scheme F) when the cost weight exceeds 0.2. On the other hand, with a broad gauge, the optimal solution remains Scheme F for cost weights between 0.2 and 0.4, transitioning to full-rail transportation (Scheme H) when the cost weight exceeds 0.4. This pattern is consistent across scenarios involving on a comprehensive dry, snow or icy pavement surfaces.

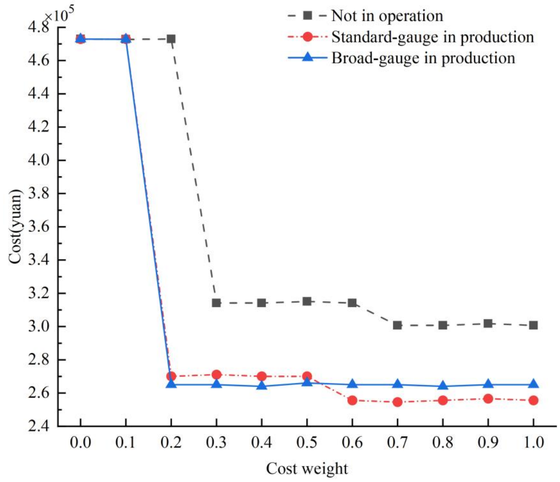

Fig.10. Changes in the minimum transportation cost with cost weight before and after the operation of the China-Kyrgyzstan-Uzbekistan Railroad on a comprehensive snow pavement

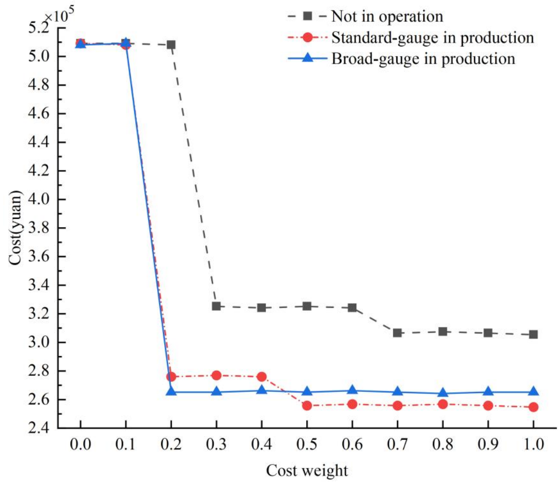

Fig.11. Changes in the minimum transportation cost with cost weight before and after the operation of the China-Kyrgyzstan-Uzbekistan Railroad on a comprehensive icy pavement

Figures 8 to 11 respectively depict the variations in transportation costs with changes in cost weight on entire dry, rainy, snowy, and icy road surfaces. Figures 12 to 15 respectively illustrate the variations in transportation time with changes in time weight on entire dry, rainy, snowy, and

TABLE XI

COST SAVINGS IN THE OPTIMAL TRANSPORTATION SCENARIO AFTER THE COMMISSIONING OF THE CHINA-KYRGYZSTAN-UZBEKISTAN RAILROAD UNDER DIFFERENT ROAD CONDITIONS

Path condition	Cost weights corresponding to the largest cost savings for standard track	The maximum saving rate corresponding to the standard track	The conventional savings rate corresponding to the standard track	Cost weights corresponding to the largest cost savings for broad-track	The maximum saving rate corresponding to the broad track	The conventional savings rate corresponding to the road track
Total dry pavement	0.3	30.6%	12%	0.4	8.5%	8.4%
Total water pavement	0.2	39%	15.3%	0.3	12.6%	12.3%
Total snow pavement	0.2	42.9%	18.6%	0.2	43.9%	15.6
Total icy pavement	0.2	45.7%	20.8%	0.2	47.8%	17.9%

TABLE XII
TIME SAVINGS IN THE OPTIMAL TRANSPORTATION SCENARIO AFTER THE COMMISSIONING OF THE CHINA-KYRGYZSTAN-UZBEKISTAN RAILROAD UNDER DIFFERENT ROAD CONDITIONS

Path condition	Time weights corresponding to the largest time-saving	The maximum saving rate corresponding to the standard track	The maximum saving rate corresponding to the broad track
Total dry pavement	0	16.9%	18.6%
Total water pavement	0.1，0.2	16.6%	18.7%
Total snow pavement	0，0.1，0.2，0.3	17.3%	18.9%
Total icy pavement	0，0.1，0.2，0.3	16.1%	17.5%

icy road surfaces.

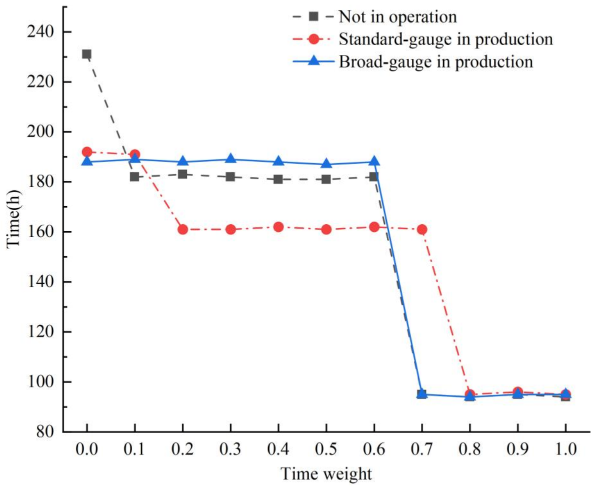

Fig.12. Changes in the minimum transportation time with time weight before and after the operation of the China-Kyrgyzstan-Uzbekistan Railroad on a comprehensive dry pavement

The most significant changes in transportation costs are observed on the fully icy road surface, decreasing from the initial peak of 5,100,000 CNY to the final low of 325,000 CNY. Correspondingly, the changes in time follow a similar trend, decreasing from an initial 286 hours to a final 148 hours. Under dry or rainy conditions, the standard gauge freight cost consistently remains lower than the broad gauge cost, while under snowy or icy conditions, the costs for broad gauge and standard gauge alternate. It is noteworthy that each curve undergoes two substantial changes, attributed to alterations in the optimal route or transportation mode.

Tables XI and XII present the post-commissioning cost and time savings for the China-Kyrgyzstan-Uzbekistan Railroad.

After the introduction of this railway into operation, regardless of whether it is a standard gauge or broad gauge railway, when the cost weight is set above 0.1, there is a noticeable reduction in transportation costs. In each of the four conditions, the standard gauge exhibits maximum cost savings rates of 30.6%, 39%, 42.9%, and 45.7%, respectively. Similarly, the broad gauge demonstrates maximum cost savings rates of 8.5%, 12.6%, 43.9%, and 47.8%, respectively. The cost savings rate increases with the escalation of rain and snow conditions. Following the sequence of entire dry, rainy, snowy, and icy conditions, the maximum savings rate for costs after commissioning gradually increases.

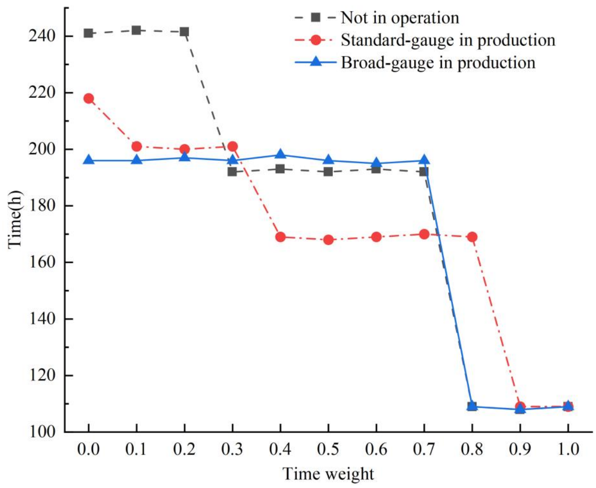

Fig.13. Changes in the minimum transportation time with time weight before and after the operation of the China-Kyrgyzstan-Uzbekistan Railroad on a comprehensive water pavement

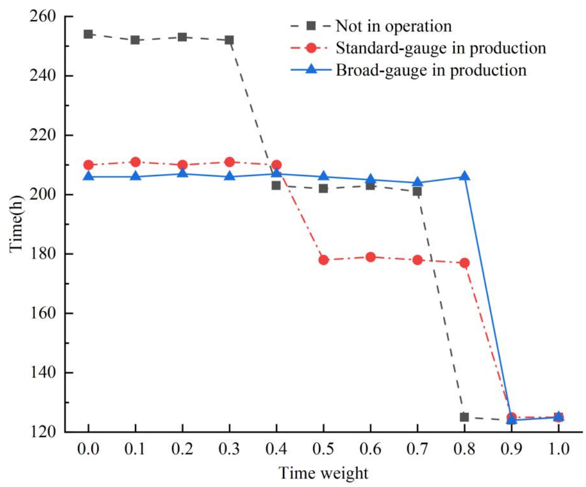

Fig.14. Changes in the minimum transportation time with time weight before and after the operation of the China-Kyrgyzstan-Uzbekistan Railroad on a comprehensive snow pavement

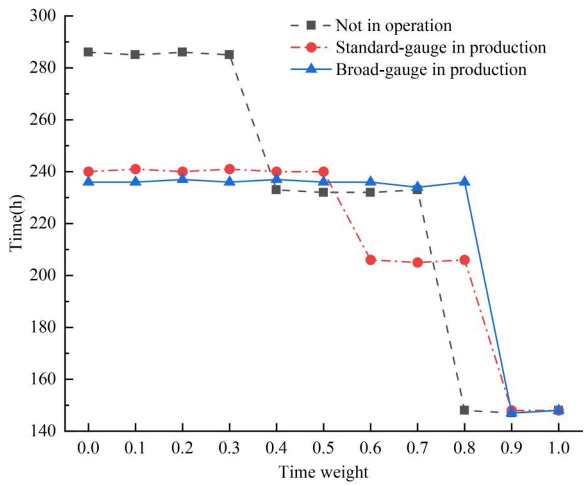

Fig.15. Changes in the minimum transportation time with time weight before and after the operation of the China-Kyrgyzstan-Uzbekistan Railroad on a comprehensive icy pavement

The post-commissioning transportation time curves for this railway alternate with those of the pre-commissioning period. When the time weight is relatively small, the optimal post-commissioning solutions showcase time savings; however, there is no discernible pattern in time savings when the time weight is large. Under snowy and icy conditions, time weights below 0.4 consistently yield the maximum time savings rate. Conversely, in dry and rainy conditions, the time weights associated with achieving the maximum time savings rate are comparatively scarce.

V. CONCLUSION

1) Cargo value, cargo damage during transportation, and rain and snow conditions are comprehensively addressed in this paper. Through the formulation of a single-objective optimization model, the total transportation cost is weighted and aggregated, incorporating container rental expenses and cargo damage costs, alongside the overall transportation time. These weightings can be adjusted by carriers based on their preferences for cost and time, facilitating the selection of an appropriate transportation strategy.

2) The study reveals that rain and snow conditions not only amplify transportation costs and duration but also lead to adjustments in the transportation strategy. Furthermore, the optimal transportation solution is influenced by the weighting assigned to cargo value and the trade-off between cost and time.

3) Following the operationalization of the China-Kyrgyzstan- Uzbekistan Railroad, substantial benefits arise when prioritizing cost weight. This is evident in noteworthy reductions in transportation costs, coupled with improvements in transportation punctuality. Simultaneously, the distinct choice between broad and standard gauges also plays a pivotal role in shaping the final transportation strategy.

4) After the China- Kyrgyzstan- Uzbekistan Railroad commenced operations, there was a significant increase in the cost savings rate in transportation costs with the intensification of rain and snow conditions, while there was no substantial change in transportation time.

REFERENCES

[1] D.D. Chen, Y. Zhang, L.P. Gao, and Russell G.Thompson. "Optimizing Multimodal Transportation Routes Considering Container Use," *Sustainability*, vol. 11, no. 19, pp5320-5320, 2019.

[2] Y.P. Lu, F. Chen, and P. Zhang, "Multiobjective Optimization of Multimodal Transportation Route Problem Under Uncertainty," *Engineering Letters*, vol. 30, no. 4, pp1640-1646, 2022.

[3] Q. Huang, H.Z. Zhang, and J.H. Yang, "Hybrid Harris hawk optimization algorithm for solving low-carbon multimodal transportation problem with fuzzy demand," *Application Research of Computers*, pp1-9, 2023.

[4] Z. Yang, L.B. Deng, Y.Z. Di, and C.L. Li, "Multimodal transportation route optimization based on fuzzy demand and fuzzy transportation time," *Control Theory and Applications*, pp1-9, 2023.

[5] M.T. Mei, X.Z. Mi, and X.J. Zheng, "Path optimization algorithm for container multimodal transportation based on DE and NSGA-II," *Modern Electronics Technique*, vol. 42, no. 15, pp144-149, 2019

[6] X.P. Deng, L. Chen, and S.H. Tian, "Multimodal transport path optimization considering mixed time windows under uncertain demand," *Journal of Chongqing University of Posts and Telecommunications*, vol. 33, no. 4, pp689-698, 2021.

[7] H.D. Tang, F.Q. Lu, L.Z. Wang, S.X. Wang, and H.L. Bi, "Improved Crow Algorithm for Soft Time Window Multimodal 4PL Routing Problem," *Computer Engineering and Applications*, vol. 58, no. 3, pp274-281, 2022.

[8] G.W. Xiong, and Y. Wang, "Optimization algorithm of multimodal transportation with a time window and job integration of multi-agent," *Journal of System Engineering*, vol. 26, no. 3, pp379-386, 2011.

[9] X. Zhao, X.F. Zhu, "Y. Zhang, Path robust optimization of green multimodal transportation considering service priority," *Journal of Shanghai Maritime University*, vol. 43, no. 3, pp21-27+82, 2022.

[10] Y. Sun, M. Hrusovsky, C. Zhang, and M.X. Lang, "A Time-Dependent Fuzzy Programming Approach for the Green Multimodal Routing Problem with Rail Service Capacity Uncertainty and Road Traffic Congestion," *Journal Citation Reports*, pp1-22, 2018.

[11] S. Liu, W. Su, Y. Peng, Y.M. Shao, and M.L. Le, "Optimization of Reliable Routes for Multimodal Transport of Emergency Supplies Under Dual Uncertainty," *Journal of Transportation Systems Engineering and Information Technology*, vol. 23, no. 1, pp58-66, 2023.

[12] Z.W. Zhang, C.F. Zhu, K.R. Liu, and Q.R. Wang "Bi-level Optimal Scheduling of Emergency Materials Considering Multimodal Transport," *Engineering Letters*, vol. 30, no. 2, pp494-505, 2022.

[13] T. Gräbener, A. Berro, and Y. Duthen, "Time-dependent multiobjective best path for multimodal urban routing," *Electronic Notes in Discrete Mathematics*, vol.36, pp487-494, 2010.

[14] M.L. Chen, X.J. Zhao, X.G. Deng, C.J. Zheng, and M.Q. Du, "Multimodal Transport Path Optimization under Uncertain Conditions," *Journal of Highway and Transportation Research and Development*, vol. 38, no. 1, pp143-150+158, 2021.

[15] J. Li, B. Yang, and X.L. Zhu, "A Green Intermodal Transportation Stochastic Optimization Strategy," *Journal of Transportation Systems Engineering and Information Technology*, vol. 18, no. 4, pp11-18, 2018.

[16] Li. Li, L.Y. Huang, and L.L. Mu, "Uncertainty for route selection in green intermodal transportation under hub congestion," *Journal of Railway Science and Engineering*, vol. 19,no. 7, pp1854-1861, 2022.

[17] X.M. Yuan, Y.D. Jiang, and X. Zhang, "Research on Robust Optimization of Interval-based Fuzzy Multimodal Transport Paths under Low-Carbon Policies," *Industrial Engineering and Management*, vol. 26, no. 4, pp134-141, 2021.

[18] X. Zhang, J.Y. Liu, X.M. Yuan, and Y.D. Jiang, "Selection of Multimodal Transportation Route Considering Scale Economy under Different Carbon Emission Policies," *Industrial Engineering and Management*, vol. 27, no. 4, pp22-31, 2022.

[19] Z.F. Wang, C.F. Zhu, and J.H. Fang "Optimization of Traveler Intermodal Transport Routes Considering Carbon Emissions," *Engineering Letters*, vol. 31, no. 3, pp1255-1264, 2023.

[20] C. Peng, "Research on international multimodal transport logistics routing based on the characteristics of cargo value," *Monthly Price Magazine*, pp83-87, 2019.

[21] G. Ren, C. Liu, Z.Y. Gao, and M.J. Ji, "The Route Selection Optimization of China-Europe Electronic Products Multimodal Transport Considering Multicycle and Mixed Time Window," *Systems Engineering*, vol. 37, no. 6, pp67-73, 2019.

[22] C. Liu, X.T. Guan, J.W. Zhang, and M.J. Ji, "Study on the route optimization of China-Europe laptop multimodal transport considering time value cost," *Journal of Railway Science and Engineering*, vol. 16, no.9, pp2352-2359, 2019.

[23] W.Y. Chen, H. Gong, and X.P. Fang, "Multimodal transportation route optimization considering transportation carbon tax and quality commitment," *Journal of Railway Science and Engineering*, vol. 19, no. 1, pp34-41, 2022.

[24] Y. Lu, X.F. Xu, C.Z. Yin, C.L. Li, and L.H. Tang, "Multi-Objective Chance-Constrained Programming of Railway Cold Chain Logistics," *Journal of Tongji University*, vol. 49, no. 10, pp1407-1416, 2021

[25] F.L. Feng, X.G. Kong, and Q.F. Wu, "Research on the route selection of international container multimodal transportation considering risk," *Journal of Railway Science and Engineering*, vol. 18, no. 10, pp2761-2768, 2021.

[26] Y.M. Li, X.Y. Guo, and L. Yang, "Route optimization of China-EU container multimodal transport considering various factors," *Journal of Railway Science and Engineering*, vol. 14, no. 10, pp2239-2248, 2017.

[27] H.X. Deng, and Y.J. Song, "Multi-objective route planning for multimodal transportation considering carbon emissions," *Journal of Chongqing University of Technology*, vol. 36, no. 11, pp219-225, 2022.

[28] J.L. Yuan, Y. Wang, and M.Q. Shen, "Analysis on Multimodal Transport Cost Efficiency—A Case Study of China, Kyrgyzstan and Uzbekistan," *Journal of Highway and Transportation Research and Development*, vol. 37, no. S1, pp75-79, 2020.