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Selection of Rail Station Locations on an Intercity Route Regarding Maximum Users' Economic Profits

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ABSTRACT
Cities located on a path of intercity railroads tend to be in a corridor system to increase commerce and economic profits. Theoretic and practical work concerning train station locations can be used to provide factors that affect the choice of train station sites. In this paper, we find optimal places to locate train stations according to location theories and particular natural and socioeconomic characteristics. The methods we used are focused on maximising users' economic profits associated with passenger and cargo transportation by finding optimal stations on the route. Furthermore, we created a general algebraic modelling system (GAMS) with linear planning, which is solvable using a C programming language (CPLEX) interactive optimiser. Case studies on 14 stations along the 820 km long Milak-Chabahar corridor helped us to simulate our model and test its feasibility at three alternative times to prove the outcomes. The stations would increase an average profit of 38.6%, 42.94% and 50.85%, but the growth varied in the stations. This research contributes to freight and passenger transportation engineers in railroad design. They benefit from the model to determine the location of a train station to obtain maximum user profits in that station and its surrounding areas.

KEYWORDS
train station location; maximum profits; railroad planning; reference rate of passengers; reference rate of cargo; mathematical modelling.

1. INTRODUCTION

Designing the route of railways and finding the optimal location of train stations along it is a challenging task. This subject has always been discussed and associated with the planning of sustainable transportation systems. Sustainable transportation systems and their railroad infrastructure planning, designing and construction require socioeconomic, environmental and technological analysis. Designing sustainable railroad infrastructure systems requires careful consideration of the resulting social impacts, economic outcomes and local development.

Determining the location of stations is a challenging task and should be carried out with much thought regarding the railroad design. Previous work has shown that finding an optimal route for railways is a design problem that causes competition and even social conflict between towns and villages along it. People in cities and counties often expect a large project such as a regional corridor to help their economy and trade with other regions. Train stations for the beneficial transportation of cargo and passengers should be located in optimal sites at the beginning of the design process.

Planners who make decisions about on-site selections for train stations should know the factors that have an impact on the economy of those places. Strategic policies, travel scheduling programs, origins and destinations of travel, freight and passenger services, as well as the cost of services influence the railroad station location. Local population and agricultural, industrial and mineral products affect the selection of the place. Additionally, the export and import of goods and tourist and cultural industries are among the privileges that affect the selection of a site for a station. Usually, political contests such as the promises of parliamentary candidates and social and ethnic groups influence the choice of places for train stations and the route of the railroad crossing. A factor in the selection of train station location is the rate of users' economic profits. Strategic policies of the railroad system, train timetables and schedules have direct associations with the rate of users' economic profits generated from the railroads.

Although various studies have examined the location of rail stations and their impact on regional economic development, the focus has not been on the location of train stations. The research on the location of train stations of the Milak-Chabahar corridor in Sistan and Baluchistan is inadequate too. The designers should take into account the factor of users' economic profits when choosing the train station locations. Therefore, taking into account the factor of users' economic profits when choosing the train station location during the initial planning and design phase is a novel concept presented in this paper. This study conducts analysis using a mathematical model and field studies to find places for train stations on the railroad route and to obtain maximum users' economic profits. Finding a desirable site for a train station on an intercity railroad route is related to maximising passenger and cargo transportation while minimising railroad construction costs. We address what principles should determine the location of train stations along the route. Our goal is to find 14 suitable sites for train stations along the corridor route and maximise the users' profits in the communities around the stations. The methods to pursue this goal include reviewing global experiences and literature about designing railroad systems.

General algebraic modelling analysis (GAMS) with linear planning, solvable by a C programming language (CPLEX) optimiser, is also conducted to achieve this goal. Case studies on the 820 km long Milak-Chabahar corridor in Iran assist us in simulating our model and testing its feasibility at three alternative times and obtaining trustable outcomes.

The outcomes of this research contribute to freight and passenger transportation engineers in railroad design. Designers can apply the model to determine the location of train stations to obtain maximum user profits regarding the stations and their surrounding areas.

2. THEORETICAL STUDIES

We plan and design a new railroad by taking into account strategic policies such as linking a port to external and interior transportation networks, and commerce with surrounding countries. A new railroad shortens existing paths and increases the speed of transportation activities [1-2]. Our literature review shows that the effects of international corridors on the economies of developing cities like Chabahar have not been sufficiently analysed so far. Recently, an article has been published about the modernisation of Chabahar Port's transport system, which is an international corridor. It aims to modernise and empower the urban transportation system and respond to the ever-increasing need for international transport services [3]. Of course, modernisation affects the growth of urban and household economies in Chabahar. However, the mentioned article has not focused on the location of stations to improve the economy of developing cities located on the path of corridors. As mentioned in the introduction section, we answer this need to explore opinions on finding optimal locations for building train stations. We aim to improve the economies of cities through freight and passengers that pass the stations and railroads.

Engineers of railroad design consider local characteristics such as soil mechanics, morphology, economy, demography and strategic policies to construct a new railroad. Scholars stated that land use policies and travel behaviour should be considered in the planning of railroad transportation networks. Railroad designing applies location theories and examined methods [4, 5]. From technical and aesthetic viewpoints, scientists and engineers analyse natural resources such as water, plants and forests along the railroad route. To design an aesthetically appropriate station, designers of railroads and train stations use natural resources and the morphology of the earth. Some scholars promote exosystemic integration with other techniques as a discipline of design [6]. Furthermore, demographic features and construction and operational costs of train stations are significant factors in designing railroad networks.

The location of intercity train stations along an international railroad should respect the economic, natural, climatic and social characteristics of cities and villages along the corridor. The selection of a train station site should also consider location theories. One applied theory is the central place theory, which is an urban geographic theory. The theory explains the number, size and range of market services connected to a train station [7]. Concerning the principles that should be considered in the process of train station location selection, Kaewunruen and Xu constructed a 3D model of King's Cross station. Their model included three groups of factors: external architecture, structural standards and interior components [8]. Additionally, socioeconomic factors impact the choice of location for train stations. For example, railroad transportation in Lithuania plays an important role in regional socio-economic development. It has been a key facilitator and driver of economic prosperity in the country [9]. An empirical exploratory analytic study was conducted in the United States. It surveyed the state of Texas to identify the progress of railroad construction. The study considered transportation requirements for better service with lessons learned from Texas [10]. Notably, the selection of location, construction and operation has had multiple effects on that place and its surrounding areas. The node-place--accessibility index analysis by Cummings and Mahmassani indicated positive impacts of stations on local economies with passenger and freight movement through the stations. In each case, node, place and accessibility quality indices exhibit the number of travellers [11]. The same source confirms that local neighbourhood characteristics influence travellers and freight transportation with more job opportunities. This fact indicates that stations are in more job-focused neighbourhoods.

The location of a train station has multiple economic, social and environmental effects on the site and its surroundings. This fact has been observed in Madrid when firms' location pattern is a consequence of multiple factors, including firm considerations, labour force availability, market opportunities and transportation costs. These factors reflect changes in stations with new transportation infrastructure [12]. Additionally, the diversity of train stations' impacts on Tokyo was associated with transport density there. The diversity of train stations in all radii examined revealed positive impacts on local economies [13]. Moreover, it can be examined what indicators railroad designers consider for the location of intercity train stations. The International Union Railway (UIC) declared a train station as a city within a city and suggested the following indicators for selecting its place: sustainability, technology, security and safety, social equity, economic growth and saving the natural environment [14]. Railroad planners may consider indicators that would lead to lower costs for the operations of stations and freight and passenger transportation. Nevertheless, lower funding may cause undesirable outcomes in the provision of transportation services. Procedures to reduce costs may decrease the reliability of transportation quality, entail additional costs for technical means and lower profitability [15]. More train stations increase overall travel and freight transit time. Fewer stations and stops reduce the overall travel time. A trade-off or balance between these objectives would yield the optimal number and location of stations. Using a multi-objective nonlinear model when designing a railroad maximises economic benefits and minimises cargo and passenger transit time. In railroad design, avoiding environmentally sensitive land and other requirements such as interstation distance, travel time between intended stations and local demographic features represent constraints [16]. From the construction viewpoint, as Wang and colleagues stated, engineers consider the following physical factors during site selection for a railroad station: drainage, water supply, future potential for development, suitable and standard gradient, correct horizontal alignment, vertical alignment, accessibility, visibility and facilities. The link between transportation and development is one of the most solidly anchored targets in economic development on any scale. The magnitude of investment in infrastructure and its reversibility is a critical factor in railroad design. It is crucial to clarify whether the cost of construction contributes to the development of the regions where the investors provide funds. The economic impacts of inter-city train stations in the local community and surrounding areas are as follows: construction effects, short-term supply-side effects, short-term effects on local demand and medium-term and long-term effects [17]. The planning and construction of the railroad would cause land use development and changes at stations and corridors. Studies in China have shown that rail transport and effective transit-oriented development can promote sustainable urban development [18]. Additionally, Chen and Hall studied the impact of high-speed trains on British economic geography. They used two indicators – gross value added (GVA), which is a key indicator of local performance, and gross household disposable income (GDHI), which indicates the wealth of resident populations. They found positive impacts of train stations on British economic geography [19]. Projects for the optimal location of train stations have been planned to maximise the users' economic benefits in train stations. These projects convert the railroad stations into innovative community hubs [20-22]. Location theory is within the scope of regional and spatial economics because it studies the types, places and logic of economic activities. In 1825, a location theory for agricultural requirements was formulated by Van Thanon. Later, in 1885, the theory was developed according to the requirements of the industrial epoch. Factually, in 1909, Alfred Weber set the scientific framework of the location theory for industrial requirements [23]. Although location theories minimise production costs, later scholars proposed theories to locate manufacturers in a place with maximum profits. From a mathematical modelling perspective, location theories are divided into four groups: First, the minimum distance model minimises production and transportation costs. Second, the maximum density model plans the location of services near population hubs. Third, the minimum power distance model declines costs by loading travel costs on customers through the nearest service centre. Fourth, the model of maximum coverage maximises the number of passengers and the weight of cargo [24, 25]. Thus, location theory selects a single site that effectively improves the economies of both the railroad system and the train stations as follows:

- cost minimisation is the process of reducing expenditures on unnecessary or inefficient processes; these changes in the reduction in costs will likely dramatically affect maximising profits
- the maximisation of economic benefit is the short or long-run process and leads to the highest profit [26–28].

The railroad can be designed according to two approaches: in one method, train stations shall ensure services to demand points surrounding the assigned transport corridor. This procedure is known as maximal coverage with the shortest path model. Another approach is to locate the stations so that the travel distance between the demand regions and the nearest station on a line is minimised. This technique is known as the median shortest path model [29–31].

3. CASE STUDIES AND METHODOLOGY

3.1 The Milak–Chabahar railroad

The Transport Corridor Europe–Caucasus–Asia (TRACECA) connects Iran to Europe, Central Asia and the Oman Sea in the south [32]. TRACECA originates from Eastern Europe and after crossing the Black Sea enters the ports in Georgia. The TRACECA route then uses the Caspian Sea ferries to Baku and reaches the railway networks of Central Asian countries. This corridor develops economic, transportation and commercial relations between the countries of the Black Sea, Caucasus and Caspian Sea basins. The Sarakhs–Chabahar corridor connects Iran to Central Asia in its north and the Oman See in its south. *Figure 1* shows the entire Sarakhs–Chabahar corridor.

Figure 1 – Chabahar–Zahedan–Milak–Sarakhs corridor [32]

In *Figure 1*, the Sarakhs–Milak–Chabahar railroad is 1,580 km long and has two parts: Sarakhs–Milak and Milak–Chabahar. The Sarakhs–Milak part in *Figure 1* is 760 km long and connects Milak to Birjand, Mashhad, Sarakhs and finally to Ashgabat in Turkmenistan. In *Figure 1*, railroads have been planned and built to expand communication and trade between people and economic enterprises of the cities on the paths. The southern branch of those corridors spans from east to west and north to south Iran. *Figure 1* also shows the Milak–Chabahar part, which is 820 km long, and the subject of this research. Our task is to find optimal locations for train stations along the Milak–Chabahar corridor. The Milak–Chabahar railway line passes through the villages and cities of Sistan and Baluchistan province. The Milak–Chabahar railroad connects Chabahar to Milak on the border of Afghanistan. The corridor is the shortest route between central countries of Asia due to its proximity to them and access to the Indian Ocean and Oman Sea. The Milak–Chabahar corridor is a transit route in the eastern part of Iran and facilitates transit between the Oman and Caspian seas. The corridor contributes to regional development and reduces the distance between Central Asian countries and the Southern

Seas. The corridor is a geopolitical factor for India, Afghanistan, China and other countries. The people along the route of the railroad have always wished to sell their products in near and far markets through railroad transportation. Chabahar City consists of two ports – Kalantari and Beheshti. The development of Chabahar and the increase in its loading capacity up to 8.5 million tons show the importance of the Chabahar–Zahedan–Milak railroad line [33]. The cities of Iranshahr, Zahedan and Zabol on the route of this railroad have diverse and significant agricultural, horticultural, livestock, industrial and mining productions. In the train stations of these cities, strategic transportation centres help the economic development and income of households. Using a mathematical model, our case studies examined the problem of the optimal selection of train station places on the Milak–Chabahar corridor. Case studies have been conducted in cities, villages, communities and potential station locations along the 820 km long strip to build an applicable mathematical model. Initially, 83 train stations were candidates to be included in the corridor system. From an infrastructure viewpoint, the Milak–Chabahar railroad has 132 large and small bridges with a total of 10,864 meters, and 32 tunnels 13,750 meters long. On 2 May 2023, Iranian officials put the current physical progress of the project at 57 per cent, saying that 70 per cent of the baseline for the railway has already been laid [34]. Debates and lobbying about the designated locations of the stations are going on, which shows the importance and timeliness of this article. We should find locations of train stations in the first phase of railroad planning, particularly, the potential station locations for the origin and destination nodes of the corridor [33].

3.2 Methods and data

From a methodological perspective, the problem examined in this paper is to find optimal locations from an economic profit perspective for train station users. We describe how to maximise the users' economic profits in every station and railroad. Every station is assumed to impact its peripheral areas as well. Users' profits in every station on the route of the Milak–Chabahar railroad have been measured using data published by the relevant authorities. Because this corridor should increase rail transportation, each train station has an extensive network of landways to transport products from production centres by truck and to send them to their destination by train. For the participation of private sector companies with public sectors, the calculation of transportation costs and guaranteed delivery to customers plus the profit of transportation companies has been conducted [35]. This method is creative and based on scientific theories and principles that improve urban and regional economies. In corrupt and demagog regimes, this method determines the location of train stations, without considering election promises and hidden conflicts, and consequently positively influences urban sustainability. To assess the effect of a station on the community surrounding it and the partner economic enterprises, we started field studies in July 2020, which continued for 24 months until August 2022. We gathered data and information through structured interviews with the Milak–Chabahar railroad project actors. We interviewed the project manager, mayors of the municipalities along the route, the chamber of commerce and the association of economic cooperatives of the border residents. To calculate the users' economic profits, we considered cargo and passenger transportation data. We collected data that present the equivalent average cargo per weight and passengers per number passed over a 24-hour period. The following chart exhibits the methodological process of choosing station location with a goal to optimise the users' economic benefits.

3.3 Mathematical modelling

By considering the flowchart in *Figure 2*, we build a mathematical model. The model assists us in calculating the users' economic profits from every train station and the entire corridor. For this reason, we pursue the following steps.

First, the railroad has been divided into segments with stations, and in every station, the economic impact of the corridor on the users is determined. To calculate the users' economic benefits, we introduce the variables that have been used in our calculations. *Table 1* presents the variables used in the definition of users' economic benefits.

The second step is to calculate the references for the cargo and passengers passing from every train station. The reference rates are available from a baseline supplied by the data on the train station in the transportation infrastructure administration. The equivalent continuous users' economic profits are measured within a 24-hour period. We assessed the users' economic profits by the cognition of the reference rate of cargo passing

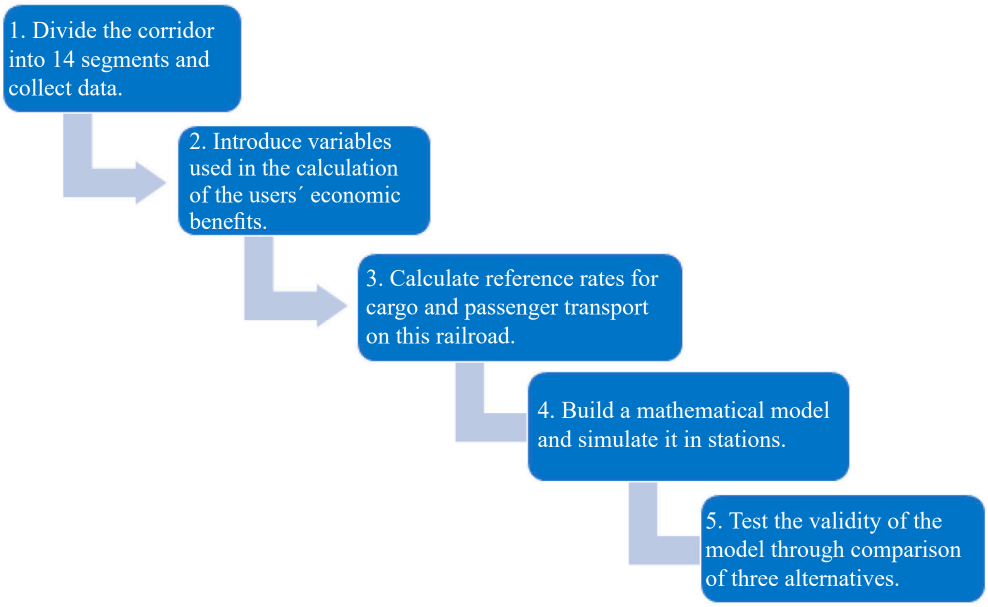

Figure 2 – The methodological process of this study

Table 1 – Variables used in assessing Milak–Chabahar corridor users' economic benefits

Variable sign	Explanation
C_i	Users' economic profits by cargo passing from station *i*
P_i	Users' economic profits by passengers passing from station *i*
C_1	Users' economic profits by cargo passing from station 1 located in Chabahar
P_1	Users' economic profits by passengers passing from Station 1 located in Chabahar
⋮	⋮
C_6	Users' economic profits by cargo passing from station 6 located in Dashtyari
P_6	Users' economic profits by passengers passing from station 6 located in Dashtyari
⋮	⋮
C_{83}	Users' economic profits by cargo passing from station 83 located in Milak
P_{83}	Users' economic profits by passengers passing from station 83 located in Milak
$\sum_{i=1}^{n} C_i$	Total users' economic profits by cargo passing from the Chabahar–Milak railroad
$\sum_{i=1}^{n} P_i$	Total users' economic profits by passengers passing from the Milak–Chabahar railroad
RCP	The reference rate of cargo passing from a station
RPP	The reference rate of passengers passing a station
W_C	The weight of cargo passed from a station in a 24-hour period
N_P	The number of passengers passed from a station in a 24-hour period
$\sum W_c$	The total weight of cargo passed from the Milak–Chabahar railroad in a 24-hour period
$\sum N_p$	The total number of passengers passed from the Milak–Chabahar railroad in a 24-h period

(*RCP*) and the reference rate of passenger passing (*RPP*) through the station by the following two functions. *Equations 1 and 2* are cargo and passenger transit over the corridor from the stations:

$$\begin{cases} C = RCP + 14\ \log_{10} W_C & (1) \\ P = RPP + 14\log_{10} N_P & (2) \end{cases}$$

where W_C is total weight of cargo in 24 hours and N_P represents total number of passengers in 24 hours.

Equations 1 and 2 are general applications of a logarithmic function, which describes the relation between users' economic profits and the rate of passengers and cargo passing through the station. We apply *Equations 1 and 2* to calculate users' economic profits *C* and *P* in each of the train stations and the entire Milak–Chabahar railroad. The railroad depended on a set of 14 train stations. The following sites have been recognised as optimal places to build train stations: {1, 6, 9, 12, 17, 24, 33, 50, 59, 64, 66, 70, 78, 83}.

These places have been selected as the best sites according to location theories and local cognitions. The model is also programmed in GAMS (general algebraic modelling system) and solved using CPLEX interactive optimiser running on the Microsoft Windows operating system. The solution produced is given as follows: 1→ 6 → 9 →12 →17 → 24 → 33 →50 →59 → 64 → 66 →70 →78 →83, where the origin of the rail line starts at node 1 (Chabahar), and the destination node is 83 (Milak). We simulate *Equations 1 and 2* for the Chabahar train station as follows:

$$C_1 = RCP + 14\ \log_{10} W_{C_1} \tag{3}$$

$$P_1 = RPP + 14\log_{10} N_{P_1} \tag{4}$$

where W_{C_1} is weight of cargo during 24 hours passed from station 1 and N_{P_1} represents total number of passengers in 24 hours on 1.

We can simulate *Equations 1 and 2* in every station likewise Chabahar's station. We calculate the users' profits for the entire railroad with its 14 stations as follows:

$$\sum_{i+1}^{n} C_i = RCP + 14\log_{10} \sum W_C \tag{5}$$

$$\sum_{i+1}^{n} P_i = RCP + 14\log_{10} \sum N_P \tag{6}$$

where $\sum W_C$ is the total weight of cargo passed the railroad in 24 hours and $\sum N_P$ is the total number of passengers passing the railroad in 24 hours.

Our mathematical optimisation model with field studies finds the most suitable train station location associated with the maximum users' economic profs. The model finds the optimum sites for our train stations on the path of the corridor. The model applies the methods of the analytical hierarchy process (AHP) and three main criteria:

- the railroad-related criterion connects 14 stations to the multimodal transportation infrastructure
- the cargo and passenger services criterion from an economic profit point of view is adaptable to our logarithmic functions for maximising the two dependent variables C_i and P_i
- simulating criterion in which the model is applicable in similar projects as has been developed in this study; such simulations contribute to the authorities that deal with the planning, design and operation of long-distance rail routes.

To develop an objective function with its constraints from *Equations 1 and 2*, we describe notations adopted in the applied model in *Table 2*.

The objective function, which has been expressed as shown in *Equation 7* maximises users' economic profits at each station location. *Equations 8 and 9* show constraints in the origin (Chabahar) and destination (Milak) stations. Meanwhile, *Equations 10–12* report the connectivity limitations between train stations.

$$Maximize \sum_{k\in K,\, g\in G} \max\left\{C_{i_{kg}}\right\} V_k \tag{7}$$

$$\sum_{k\in O} V_k = 1 \tag{8}$$

Table 2 – Symbols and names of notations used in the objective function

Notation	Description
O	Set of potential origin stations
D	Set of potential destination stations
$S \in O \cup D \subsetneq S$	Set of all potential stations
$g \in G$	Set of cities that benefited economically
NS	The maximum number of stations on a railroad line
$C_i = Users'economic\ profits_{kg}$	Users' economic profits resulting from a city $g \in G$ in trains passing a potential station $k \in K$
V_k	A binary variable, which equals 1 if station *k* is selected, and 0 otherwise
X_{ik}	A binary variable, which equals 1 if potential stations *i* and *k* are connected and 0 otherwise

$$\sum_{k \in D} V_k = 1 \qquad (9)$$

$$\begin{cases} X_{ij} = V_{ij} & \forall i \in O,\ \forall j \in K \mid O \cup D & (10) \\ X_{ij} = V_{ij} & \forall i \in K \mid O \cup D,\ \forall j \in D & (11) \\ \sum_{i<k} X_{ik} + \sum_{j>k} X_{kj} = 2V_k & \forall k \in K \mid O \cup D & (12) \end{cases}$$

In *Equation 10*, the origin station is connected with another interim station on the railroad. *Equation 11* is defined to link the destination station with other neighbouring stations on the corridor. In this model, *Equation 12* shows connectivity limitations associated with interim stations (not origin or destination stations), given that these stations are connected to two other stations. In this model, there are also sub-tour elimination constraints since only a single continuous tour represents the route of the railroad corridor. The algorithm that prevents sub-tours is expressed in *Equation 13*. Please note that the domain of the variables used in the model is presented in *Equations 14 and 15*.

$$\sum_{j \in K} \sum_{i \in K,\, i \neq j} X_{ij} \leq |S| - 1 \qquad (13)$$

$$\begin{cases} Z_i \in \{0,1\} & \forall i \in K & (14) \\ X_{ij} \in \{0,1\} & \forall i, j \in K : i < j & (15) \end{cases}$$

Equations 14 and 15 present a model that can decide on optimal sites for building train stations and consequently maximising users' economic profits.

3.4 Simulation and test of the model

In the third step, we simulate the calculations to find the exact users' economic profits in every train station. *Table 3* displays the results of the simulation by determining the users' economic profits per percentage of increases in the economic profits at each train station. With comparisons of the results of three alternative times of 2019, 2020–2021 and 2021–2022, we check whether the train station has grown users' economic profits or not. In the case of an increase, our model works well, otherwise, it has errors. In 2021–2022, the average users' economic profits of the railroad route are assessed to be around 50.85%., which illustrates the users' economic profits growth in every station compared to the end of 2019 and 2020–2021.

In *Table 3*, the unit of calculation for the users' economic profits is the US dollar. According to simulated calculations, we experienced an average percentage of the profits equal to 38.6%, 42.94% and 50.85% at the end of 2019 and 2020–2021 and 2021–2022, respectively. The average users' economic profits show smooth growth in *Figure 3*.

Table 3 – Comparison of users' economic profit growth per percentage three times

The number of stations	Name of the station $g \in G$	Average users' economic profits at the end of 2019	Average users' economic profits in 2020–2021	Average users' economic profits in 2021–2022
1	Chabahar	86	88	92
6	Dashtyari	49.1	50.6	55
9	Ghasrghand	37	39.7	47
12	Sarbaz	29.5	40.2	43.9
17	Iranshahr	50	59.1	63
24	Damen	29.7	31.4	38
33	Khash	42	44.9	51
50	Nookabad	24	25.2	31
59	Zahedan	67.3	73	77
64	Hormak	25	19.2	29
66	Dorahi	12.4	22	33
70	Ramshar	15.9	24.5	39
78	Hamoon	6.1	11.3	38
83	Milak	66.6	72.1	75
Aver.	Chabahar–Milak railroad	38.6	42.94	50.85

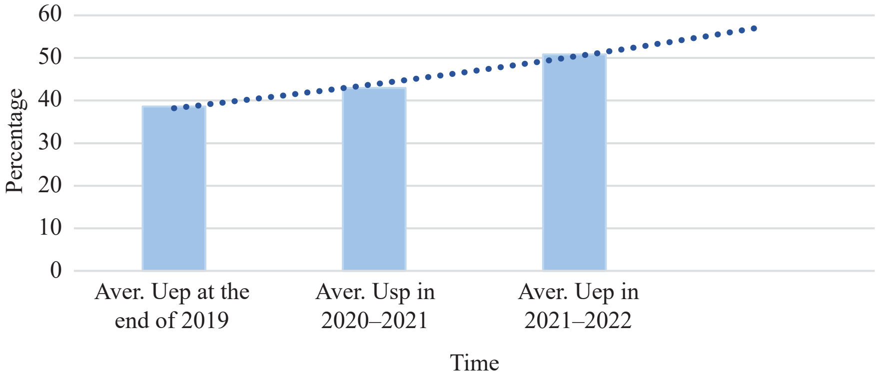

Figure 3 – Comparing the average growth of users' economic profits in 2019, 2020–2021 and 2021–2022

However, *Figure 4* below exhibits that the users' economic profit changes have been different in stations.

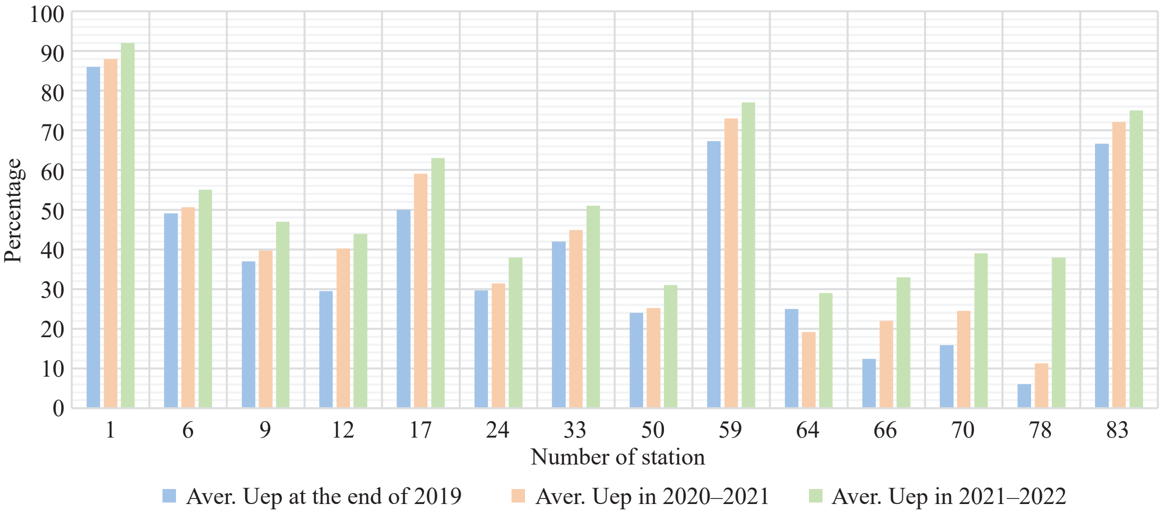

Figure 4 – Comparing the growth of users' economic profits in 14 stations and three alternative times

Figure 4 illustrates different users' economic profits in the stations. The growth of profits in the three time periods has not happened similarly. The outcomes of our simulation and comparisons between the alternatives verify the right choice of train station locations and the applicability of the mathematical model.

4. FINDINGS AND DISCUSSION

Studies concerning regional railroad design in developing cities show that the location of train stations has decisive effects on urban socioeconomic and physical development [36]. The model used to decide the location of the Milak–Chabahar train stations includes the users' economic profit maximisation. The maximisation generates the highest profit for the users from freight and passenger transportation through this long-distance rail route. The solution yielded by the proposed model is in harmony with academic theories concerning the location of train stations. Additionally, simulation of the model with field studies confirms that the selected places for 14 train stations provide socioeconomic and physical development for the cities on the path. The users' economic profit analysis is based on the average of the two different types of cargo and passenger transport. The US dollar has been applied as a common unit to calculate the users' economic profits in two categories of transportation in train stations. A comparison of three alternatives, namely users' economic profits in 2019, 2020–2021 and 2021–2022, shows that the method to locate 14 stations in this long-distance railroad has generated an average of 38.6%, 42.94% and 50.85% increase in the users' economic profits, respectively. The increases happened at high rates according to *Figures 3 and 4*. This increase is a contributor to the socioeconomic and physical development of train station locations and their surrounding communities. The results displayed in *Figure 4* exhibit differences in users' economic profits between 14 stations. *Figure 3* shows that station 1 (Chabahar) had the largest share of the income. Users' economic profits in this station increased from 85% in 2019 to more than 90% in 2022. After Chabahar, stations 59 (Zahedan) and 83 (Milak) experienced an economic profit growth of 68% to 78%. The high-profit growth in Chabahar, Zahedan and Milak was due to the use of rail transportation in international trade. Station 78 (Hamoon) experienced changes in users' economic profit growth from 17% in 2019 to 39% in 2022. This huge jump was due to the speed of prompt gathering of merchants and companies around the train station and business development. Station 66 (Dorahi) also followed the same process. The difference between the users' economic profits in the 14 stations shows that the railroad influences the sustainable development of cities and regions. Furthermore, the progress rate of trade experienced by every train station was different due to their location. The increase in users' economic profits in the 14 stations contributes to sustainable urban development, which is consistent with the theories and experiences of scientists [37, 38]. The impacts of the Chabahar–Milak railroad on 14 cities are due to its international and commercial functions, in which the origin and destination are of particular international commercial importance.

5. CONCLUSIONS

This novel and applied study addressed the selection of train station places on an intercity route to obtain maximum users' economic profits in the places and surrounding communities. This study used field studies to examine the train station location criteria and principles and to further extend the relevant theories. Then, a mathematical model was created using GAMS to select places for 14 train stations according to the maximisation of users' economic profits. The model used the optimal selection method to find 14 train station sites. The 14 train stations maximised the users' economic profits in every place through their local potential. The simulation of the model with data gathered in the case study region confirmed its applicability. The model could act as a decision-support tool for railroad designers. The locating of stations should be planned in the initial planning phases of the project to ensure a sustainable connection between cities and neighbouring countries. This study applied the model in a case study in the Chabahar–Milak corridor and solved the problem by gathering data about the railroad using CPLEX. Results revealed a 92% and 75% increase in the users' economic profits in origin (Chabahar) and destination (Milak), respectively. Even in the disparate community of Hormak, the location of the train station exhibited a 29% increase in the users' economic profits in 2022. The applied methods, proposed model and outcomes of this research assist new intercity rail line planning and design everywhere in locating train stations optimally. In the future, we shall research the planning and construction of multimodal transportation logistics centres near the train stations mentioned in this research.

REFERENCES

[1] Johansson I, Weik N. Strategic assessment of railway station capacity–Further development of a UIC 406-based approach considering timetable uncertainty. *The 9th International Conference on Railway Operations Modelling and Analysis (ICROMA), RailBeijing 2021, 3-7 November 2021, Beijing, China.* 2021. https://www.diva-portal.org/smash/get/diva2:1619837/FULLTEXT01.pdf.

[2] Johansson I. *Simulation studies for improved efficiency in road and rail freight transports*. Doctoral thesis. KTH Royal Institute of Technology; 2021. https://www.diva-portal.org/smash/record.jsf?pid=diva2:1554753.

[3] Cao B, Shahraki AA. Planning of transportation infrastructure networks for sustainable development with case studies in Chabahar. *Sustainability*. 2023;15(6):5154. DOI: 10.3390/su15065154.

[4] Chai S, Liang Q, Zhong S. Design of urban rail transit network constrained by urban road network, trips, and land-use characteristics. *Sustainability*. 2019;11(21):6128. DOI: 10.3390/su11216128.

[5] Yang C, et al. Multi-layer regional railway network and city economy: Polarization, integration, and spillover. Preprint article. 2022. DOI: 10.2139/ssrn.4109034.

[6] Qiu S, et al. Ecosystem thinking and methods in design morphology. Preprint article. 2022. DOI: 10.20944/preprints202202.0102.v1.

[7] Hu Z, et al. Unraveling the dynamic changes of the high-speed rail network with urban development: Evidence from China. *Socio-Economic Planning Sciences*. 2023;85:101380. DOI: 10.1016/j.seps.2022.101380.

[8] Kaewunruen S, Xu N. Digital twin for sustainability evaluation of railway station buildings. *Frontiers in Built Environment*. 2018;4:77. DOI: 10.3389/fbuil.2018.00077.

[9] Raslavicius L, Bazaras Z. Rail transport in Lithuania: History, development, and integration into today's European transport network. In: Kazlauskas B. (ed.) *Lithuania: Political, economic, and social issues*. 2018. p. 75. https://www.novapublishers.com/wp-content/uploads/2018/09/978-1-53614-279-2.pdf#page=87.

[10] Esmalian A, et al. Operationalizing resilience practices in transportation infrastructure planning and project development. *Transportation Research Part D: Transport and Environment*. 2022;104:103214. DOI: 10.1016/j.trd.2022.103214.

[11] Cummings C, Mahmassani H. Does intercity rail station placement matter? Expansion of the node-place model to identify station location impacts on Amtrak ridership. *Journal of Transport Geography*. 2022;99:103278. DOI: 10.1016/j.jtrangeo.2022.103278.

[12] Mejia-Dorantes L, Paez A, Vassallo JM. Transportation infrastructure impacts on firm location: The effect of a new metro line in the suburbs of Madrid. *Journal of Transport Geography*. 2012;22:236-250. DOI: 10.1016/j.jtrangeo.2011.09.006.

[13] Kumakoshi Y, Koizumi H, Yoshimura Y. Diversity and density of urban functions in station areas. *Computers, Environment and Urban Systems*. 2021;89:101679. DOI: 10.1016/j.compenvurbsys.2021.101679.

[14] Rosnarti D, et al. The characteristics of business places within Transit-Oriented Development (TOD) in Jakarta in terms of proximities to transit stations and urban centers. *Technology Reports of Kansai University – TRKU*. 2022;64(5):8015-8030. http://www.karyailmiah.trisakti.ac.id/uploads/kilmiah/dosen/the-characteristics-of-business-places-within-transit-oriented-development-tod-in-jakarta-in-terms-of-proximities-to-transit-stations-and-urban-centers-63883ffa15f3e.pdf.

[15] Olentsevich VA, Belogolov YI, Kramynina GN. Set of organizational, technical and reconstructive measures aimed at improvement of section performance indicators based on the study of systemic relations and regularities of functioning of railway transport system. *IOP Conference Series: Materials Science and Engineering*. 2020;832(1):012038. DOI: 10.1088/1757-899X/832/1/012038.

[16] Roy S, Maji A. A station location identification model for an integrated interoperable high-speed rail system. Preprint article. 2019. DOI: 10.2139/ssrn.3512289.

[17] Blanquart C, Koning M. The local economic impacts of high-speed railways: Theories and facts. *European Transport Research Review.* 2017;9(2):1-14. DOI: 10.1007/s12544-017-0233-0.

[18] Li S, et al. Spatial and temporal dynamics of urban expansion along the Guangzhou–Foshan inter-city rail transit corridor, China. *Sustainability.* 2018;10(3):593. DOI: 10.3390/su10030593.

[19] Chen CL, Hall P. The impacts of high-speed trains on British economic geography: A study of the UK's InterCity 125/225 and its effects. *Journal of Transport Geography*. 2011;19(4):689-704. DOI: 10.1016/j.jtrangeo.2010.08.010.

[20] Tiwari R. Connecting places, connecting people: A paradigm for urban living in the 21st century. 2017. DOI: 10.4324/9781315449241.

[21] Banerjee I, Saha A. Mobility center-oriented urban regeneration: Examining place value of railway stations. *Geojournal*. 2022;87(Suppl 4):567-581. DOI: 10.1007/s10708-022-10582-y.

[22] Du J, van Wesemael P, Druta O. Place quality in high-speed rail station areas. *Journal of Transport and Land Use*. 2021;14(1):1165-1186. DOI: 10.5198/jtlu.2021.1820.

[23] Marchionatti R. *Economic theory in the twentieth century, An intellectual history – Volume I*. Springer; 2020. DOI: 10.1007/978-3-030-40297-6.

[24] Raza A, Zhong M, Safdar M. Evaluating locational preference of urban activities with the time-dependent accessibility using integrated spatial economic models. *International Journal of Environmental Research and Public Health*. 2022;19(14):8317. DOI: 10.3390/ijerph19148317.

[25] Richards HA. Transportation costs and plant location: A review of principal theories. *Transportation Journal*. 1962;2(2):19-24. https://www.jstor.org/stable/20711853.

[26] Alsaedi SSA. *The theoretical and practical aspects of railway reform: Implications for Saudi Arabia*. Doctoral thesis. University of Southampton; 2023. DOI: 10.5258/SOTON/D2268.

[27] Mankiw NG. *Principles of microeconomics*. Solen ac.UK; 2009.

[28] Aparicio Á. Planning, power, and deliberation: Lessons from high-speed rail expansion in Spain. *Frontiers in High-Speed Rail Development*. 2021. p. 229.

[29] Hammad A, et al. Mathematical optimization of rail station location and route design in urban regions through minimizing noise pollution. *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*. IAARC Publications; 2018. p. 1-6.

[30] Vichiensan V, et al. Urban rail transit in Bangkok: Chronological development review and impact on residential property value. *Sustainability*. 2021;14(1):284. DOI: 10.3390/su14010284.

[31] Wei M, Liu T, Sun B. Optimal routing design of feeder transit with stop selection using aggregated cell phone data and open-source GIS tool. *IEEE Transactions on Intelligent Transportation Systems.* 2021;22(4):2452-2463. DOI: 10.1109/TITS.2020.3042014.

[32] Hamre J, et al. *Reconnecting of Asia*. Center for Strategic & International Studies; 2015. https://www.csis.org/analysis/reconnecting-asia [Accessed July, 2020].

[33] National Iranian Railway Company. *Annual report of 2020*. https://www.rai.ir/ [Accessed 15 Jan. 2023].

[34] Tehran Times. Newspaper. https://www.tehrantimes.com/news/470675/Zahedan-Chabahar-railway-to-be-completed-by-Mar-2024 [Accessed 10 Dec. 2022].

[35] Shahraki AA. *Planning and designing of Iranshahr's logistic center*. Zahedan City, Iran: Sistan and Baluchistan University, Department of Urban Planning and Geography; 2022.

[36] Sudan FK. Socioeconomic and spatial impacts of high-speed rail on enterprises: An ex-ante case study of Ahmedabad Station area, India. *Global Economics Science*. 2022;235-257. DOI: 10.37256/ges.3220221341.

[37] Herzog I. National transportation networks, market access, and regional economic growth. *Journal of Urban Economics*. 2021;122:103316. DOI: 10.1016/j.jue.2020.103316.

[38] Hu Y, Chen Y. Coupling of urban economic development and transportation system: An urban agglomeration case. *Sustainability*. 2022;14(7):3808. DOI: 10.3390/su14073808.

郭毅， 和阿卜杜勒•阿齐兹•沙赫拉基

铁路车站选址实现线路城市用户经济利润最大化——以长途铁路为例

抽象的：
本文根据区位理论，结合各城市的自然、经济、社会特点，对城际火车站进行选址，以可持续发展为目标。 城际铁路沿线或邻近线路的城市和乡村希望被纳入铁路系统，以增加其经济利润和商业扩张。 本文提出了最大化与走廊国际贸易相关的用户经济利润的方法，作为一项战略性可持续政策。 有关火车站选址的理论和经验提出了影响火车站和周围建筑环境选择的设计标准。 本文提出了通用代数建模系统(GAMS) 中的数学模型，并使用在 Microsoft Windows 上运行的 (CPLEX) 交互式优化器对其进行求解。 本文通过对恰巴哈尔-米拉克820公里长途铁路中火车站的优化选址进行仔细建模，通过14个车站的货运和旅客实现用户经济利益最大化。 三个不同时期，铁路沿线设有车站的城市平均利润增幅分别为38.6%、42.94%、50.85%。 然而，由于当地社会经济特征，14个站点的增长情况各不相同。 本文进行了案例研究，以模拟所提出的位置模型在锡斯坦和俾路支斯坦地区的适用性。 然而，其创造性和经过现场测试的程序有助于铁路设计知识并为各地的交通规划者提供帮助。

关键词：
火车站选址、利润最大化、铁路规划、旅客参考率、货运参考率、数学建模。