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Land-Use Modification Based on Transit-Oriented Development Adjacent to Historical Context (Case Study: Qazvin City)

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Abstract

Nowadays, improving public transport alone is not enough to solve urban traffic congestion, and a proper land-use planning scheme should accompany it. One of the approaches to solve this problem is mutual interaction between land-use and transportation called Transit-Oriented Development (TOD). Since Qazvin, as a historical city that was Iran's medieval capital in the Safavid dynasty (1555-1598), was selected as a pilot to implement TOD by the Ministry of Roads and Urban Development (MRUD), knowing the various aspects of this issue is essential. This paper presents the best-generated plan for land use modification around the concerned TOD stations adjacent to Qazvin city's historical areas. In this regard, a mathematical model with four objectives is developed to preserve historical context and signify optimized mixed-use using the Genetic Algorithm (GA) based on Python programming. First, maximize the density of commercial, residential, and mixed land use. Secondly, minimize the TOD skyline border to preserve the zone's historical identity. Thirdly, minimize land-use changes as much as possible to save the regions' context, and finally, increase the density of the land use allocation based on the TOD rules. In station 6, the most change related to residential decreased by about 30 percent, but at station 19, the most remarkable change related to commercial decreased about 10 percent.

***Keywords*:** Transit-Oriented Development, Genetic Algorithm, Historical Areas, Qazvin

1. Introduction

Transport growth (except public transportation growth) and the increasing number of trips are key factors contributing to the increase in environmental instability in the current urban environment. Increasing energy and fuel consumption, traffic congestion, air pollution, and the use of urban spaces to develop transport infrastructure are examples of adverse effects of transport growth [1]. Moreover, because of the growing need for people to travel by their private vehicles, especially with economic and health upgrades, transportation infrastructure has expanded enormously [2]. It has become a powerful tool for determining how cities grow. The auto-orientation development pattern has led to the random and sporadic growth of settlements, widespread suburbanization, increasing distance between communities, and decreasing urban land use efficiency. In this regard, the experts first found the solution to expanding public transportation. They believed that public transit would benefit from reducing personal car use: improved air quality and better access to jobs. Public transportation, urban design, and urban development have benefits that reinforce each other. Investing in public transit increases their value by providing more access to neighboring properties and provides new growth [3]. Urban planning experts paid attention to the integrated and coordinated urban development planning with public transportation, which reached sustainable urban development. In this research, according to one of the Transit-Oriented Development (TOD) missions in solving the traffic congestion problem, TOD areas in Qazvin city have been identified based on overlying Bus Rapid Transit (BRT) lanes and saturated links in regards to traffic assignment. Then the solution of land-use modification is proposed based on the TOD principle. Thus, we modify and optimize the land use around the selected stations, located in ancient and historical parts of Qazvin city, by an optimization algorithm. Qazvin was the capital of Iran or the Persian Empire under Safavids in 1548–1598 [4], and it is registered as an Iranian Cultural Heritage (ICH) in 2007, which is cited in the World Heritage Center (WHC) list of UNESCO. Thus, the question is what solutions can be proposed to modify and optimize the land-use arrangement around these potential stations in these historical areas since it is crucial to saving its nature after TOD implementation. Thus, in this research, we use a multi-objective mathematical model to investigate this issue by choosing the best location and reallocating the land uses around them.

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2. Literature Review

Transit-oriented development is dense, mix-used development which provides good biking and walking connections in the city, particularly areas served by transit facility [5]. In another definition, TOD can be described as land use and transportation planning that facilitates cycling, walking, and transit use and maximize the efficiency of existing public transit services by focusing development around public stations [6]. According to world studies in TOD, research in this field can be divided into two general categories. 1- The effects of implementing TOD on the structure of the city and the decisions of individuals in choosing a place of residence (effects of TOD) 2- TOD allocation by various methods and modifying land uses around transit stations (TOD planning). A very substantial amount of research efforts have already been devoted to analyzing the effects of TOD. TOD effects on various factors can be divided into 5 different parts: the effects of TOD on travel behavior, real estate prices, residential location, urban form, and community life. The background of research in the field of effects of TOD is given in Table 1. The TOD planning section can also be divided into two parts: planning policy and planning tools (systems or models). In each section, many kinds of researches have been done in the world. In this regard, the presented paper is in the subset of the second part of TOD studies (TOD planning - planning tools).

Table 1
Researches in the field of TOD effects

Reference	Category	Methodology	Case study
Nasri and Zhang (2014) [7]	effects of TOD on travel behavior	Comparative analysis/multilevel mixed-effect	Washington, D.C., Baltimore (USA)
Pan et al. (2017) [8]	effects of TOD on travel behavior	Spatial analysis/OLS regression model	Shanghai (China)
Ewing et al. (2017) [9]	effects of TOD on travel behavior	Descriptive statistics - comparative analysis	Denver, Los Angeles, San Francisco, Seattle, Washington, D.C. (USA)
Tian et al. (2017) [10]	effects of TOD on travel behavior	Descriptive statistics	Seattle (USA)
Shirek et al. (2017) [11]	effects of TOD on travel behavior	multinomial logit model (MNL)	Mumbai (India)
Park et al. (2018) [12]	effects of TOD on travel behavior	Discrete choice modeling/negative binomial model	Atlanta, Boston, Denver, Miami, Minneapolis-St. Paul, Portland, Salt Lake City, Seattle (USA)
Pongprasert and Kubota (2019) [13]	effects of TOD on travel behavior	Factor analysis/structural equation modeling	Bangkok (Thailand)
Duncan (2019) [14]	effects of TOD on travel behavior	Descriptive statistics	Charlotte (USA)
Xu et al.(2016) [15]	Real-estate price effects	Hedonic price model/spatial autoregressive model/spatial error model	Wuhan (China)
Yu et al. (2018) [16]	Real-estate price effects	Hedonic price model/spatial Durbin model/geographically weighted regression	Austin (USA)
Olaru et al. (2011) [17]	Residential location effects	Descriptive statistics - comparative analysis/discrete choice modeling (latent class and hybrid choice)	Perth (Australia)
Kamruzzaman et al. (2015) [18]	Residential location effects	Comparative analysis/discrete choice modeling (binary logit)	Brisbane (Australia)
Ratner and Goetz (2013) [19]	Urban form effects	Descriptive statistics	Denver
Zhao et al. (2018) [20]	Urban form effects	Descriptive statistics/OLS regression model	Beijing (China)
Zhao and Shen (2019) [21]	Urban form effects	multinomial logit model (MNL) / the land-use allocation model	Wuhan (China)
Kamruzzaman et al. (2014) [22]	Community life effects	Cluster analysis/simultaneous equation model	Brisbane (Australia)

2.1 Planning tools

This section examines cities and cases where TOD has not been implemented and discusses TOD and land-use modification literature. Two main research directions have been explored up to now concerning TOD planning tools: Multi-criteria decision analysis (MCDA) and multi-objective optimization (MOO). MCDA is used to rank alternative decisions according to several predefined criteria and decision-maker preferences .MOO is used to determine efficient solutions considering a set of objectives while complying with a set of constraints, with both objectives and constraints expressed as functions of the decision variables.

Amongst the few other articles that also propose MCDA tools for TOD planning, the paper highlighted by Strong et al. in 2017 was the key one [23]. In response to how a transit agency can choose between alternative TOD sites to develop, they developed a decision support tool (framework) for making such choices incorporating and assessing unique success factors and their weights. By considering 18 criteria in Denver, the Analytical Hierarchy Process (AHP) method was used. Considering the opinion of experts, the most important criteria were found to be the quality and length of the walking route to the station, the number of mixed-use structures, and the planned mixed-income housing. In contrast, parking supplies on-site, existing, or planned retail store and cultural and entertainment centers were classified as the least important. Another paper with the same approach develops a comprehensive index called "Sustainable TODness" around the four dimensions of sustainable development (environmental, economic, social, and transportation efficiency) combined with the fuzzy analytic network process (FAHP). Using this index, an evaluation of 13 TOD stations in the Tokyo metropolitan area was carried out. Each station's impedance pedestrian catchment area was spatially analyzed in conjunction with the Geographic Information System (GIS) to generate a heat map of indicators' distribution. According to the spatial characteristics reflected by the heat map, the stations are divided into three categories. They found that some popular TOD stations have high scores on the economic level, but have more or fewer deficiencies in the other three dimensions [24].

In a study by Wey et al., TOD's standard selection criteria have been formulated to meet the principle of sustainable transport. The fuzzy Delphi technique was used to select TOD evaluation criteria, and the FANP was employed to determine the weights of relevant planning criteria. The results show that all the nine TOD evaluation criteria for sustainable transport supported by an expert group in the first step of the study were critical to the TOD assessment. According to the weighted evaluation criteria, high density was the essential criterion in the second step, while equality in residence accessibility was the least decisive principle. Finally, by using the GIS, each station's performance on the Ankeng line of the New Taipei MRT system was evaluated based on TOD evaluation criteria. Combining the evaluation with the FANP weighted values showed that the Xinhe Elementary School MRT station is the TOD's optimal station [25]. Another article with the same authors classified the principles of smart growth based on literature. A team of experts consisting of six experts first assigns the main weights to each criterion. Then, six sets of scores are averaged for selecting the potential location of each station. A combined FAHP and Data Envelopment Analysis (DEA) model were applied to choose the most apposite station from a set of potential sites. Two stations have been selected and proposed for the public sector [26].

Focusing on the implementation of TOD factors in Seoul, South Korea, emphasizes that TOD planning considerations can positively affect a TOD city's formation. Instead of focusing on increasing the development density, focusing on the mixed land use index, strengthening public transport services, rebuilding street networks, and designing urban areas to improve walkability around stations are recommended [27].

By placing subway stations in underdeveloped locations, governments can afford to spend less and earn more money from future land deals. As a Shenzhen case study, the hypothesis was tested with metro planning and land exchange data samples from 2000 to 2014. The researchers found that subway routes and station locations ignored the core of communities in the area [28].

Two new multi-objective optimization models for TOD planning around transit stations were proposed recently, respectively by Sahu (2018) and Ma et al. (2018), the former to decide the types and densities of land uses along with two BRT station in a transport corridor and the latter around a transit station. The application of the models was illustrated for Naya Raipur (India) and Beijing, respectively. The objectives considered by Sahu (2018) were: maximize TOD characteristics (density of population and employment and diversity of land uses); shaping the skyline; minimize land-use change, and making land uses compact. Ma et al. (2018) considered the following objectives: maximize rail transit ridership; maximize land-use compactness (number of neighboring cells with the same land use); maximize accessibility (i.e. minimize travel time around transit stations) taking into account congestion effects; minimize conflicts between the land uses of adjacent cells, and minimize environmental effects (measured by pollution treatment costs). In both cases, some objectives were expressed by nonlinear functions of (some) decision variables, thus making the models mixed-integer and nonlinear, and therefore very difficult to tackle through exact optimization methods. Instead, both authors have used genetic algorithm. However, there is an important difference in the methods they have applied since Sahu (2018) applied weights to the objectives, thus converting the multi-objective model into a single-objective model. In contrast, Ma et al. (2018) truly tackled the multi-objective model, concentrating on the construction of the

Pareto front and the analysis of some non-dominated solutions [29], [30].

2.1.1 Planning Tools in IRAN Cities

Reviews show that in developing countries where the TOD has not been implemented yet, the main concern is finding the optimal location to implement the TOD and reform policies in the city's comprehensive plans to implement the TOD. Iran cities are also part of this category [31]. With the expansion of public transport systems such as subway and bus rapid transit, applying this new approach to urban development is crucial for improving urban problems more than ever before. The TOD plan should be included in formulating urban development plans, such as comprehensive urban plans. Thus, the proper location-allocation of public transport stations and formulation of the rules and patterns of development of neighborhoods and cities in the context of the TOD model seems essential [32]. Factors such as traffic congestion in cities, pollution caused by personal cars, lack of vitality in modern urban spaces are significant TOD trends. The critical role of this type of event in reforming access to community support for achieving regional goals is significant [33].

For instance, for finding new TODs in the city of Isfahan to decrease the volume of traffic in the city center, the criteria and indicators affecting the success of the TOD approach were identified. After collecting the necessary data, the value of each of these criteria was quantitatively evaluated in the 21 metro stations of Isfahan metro station. The result of this survey is prioritizing subway stations to develop TOD around them. Based on this study's results, three stations of Kaveh, Azadi, and Imam Hossein were selected as TOD centers. These three stations rank highest in population density, business density, work centers, travel attraction, passenger statistics, access to roads and urban highways, and public transport access [34]. In another study, the urban design of the station with the TOD approach around the Allameh Majlesi station in Mashhad was examined by Alalhesabi and Rabie [35]. Environmental quality has been measured in this station's vicinity, and concerning its strengths, weaknesses, opportunities, and threats (SWOT), prospects, goals, strategies, and policies have been formulated. Conceptual design proposals have been addressed in these same environmental qualities, followed by urban design guides with the AHP method's options. Finally, solutions to applying the TOD principles to improve urban spaces' quality within the range of transport stations will be presented. Alalhesabi and Moradi, by examining the Shiraz Subway Line 1 found that urban growth direction should be used to determine and characterize TOD and station expansion centers in Iranian cities. They point out that the proposed metrics and framework can have profound and decisive effects on enhancing the public transport network's efficiency concerning the urban form and preventing the formation of stations that waste the public transport network's potential [36].

The network analysis technique and Super-Decisions software were used for evaluating the role of the Darvazeh Dolat Station in Tehran on the TOD approach. In fact, by presenting a MCDM approach, prioritizing the effective sub-criteria in the research objective, this technique determines the Darvazeh Dolat Station Complex's role. This study showed that the Darvazeh Dolat Station Complex construction, while improving public areas' quality and reducing environmental pollution, plays a significant role in promoting public transport [37]. In another study, Rafiean and Akbari investigated urban land-use planning around the Shush subway station with the TOD approach in Tehran. This study aims to introduce land use parameters affected by the metro station's deployment and then evaluate each of these parameters' effectiveness in the study area. For this purpose, the information obtained from the municipality, aerial photos of different periods, referring to the study area, and conducting interviews with residents and practitioners in the area were used to create information layers. In the next step, after identifying the importance of each criterion and using the GIS overlap method, the affected areas could be determined. Finally, recommendations for the future were suggested, emphasizing the need to change the system [38]. Field survey and correlation analysis of Sharif metro station and Iran University of Science and Technology Station showed that public transport routes in Tehran do not have the basic features of TOD. These stations areas cannot become an active social and civic center [39]. Motieyan's research offered a four-step approach to develop a spatial TOD index. Firstly, a set of indicators for TOD planning was considered. Next, the indicators were measured at the neighborhood scale by GIS. Then, a fuzzy-AHP technique was used to aggregate the indicators. Finally, three maps were derived based on pessimistic, moderate, and optimistic views. The sensitivity analysis showed that the variety of indicators' weights in different aspects did not significantly influence the TOD levels. In the fourth step, to assess the suggested method's efficiency, the moderate TOD-level map in neighborhoods is compared with the transit services and trip attraction level. This observation shown that the TOD map had a precision of 77 percent in urban modeling [40].

It can be concluded from the researches carried out that the TOD topic in Iran has not received much attention from the transportation perspective. One of the available gaps is the lack of attention to criteria such as the volume-to-capacity ratio to choose routes for TOD implementation. Most of the TOD researches have focused on the station scale and less attention to the corridor scale. Therefore, in the first part of this research, which is finding potential areas for TOD implementation, we have tried to address these research gaps. In this regard, we used the Zargari et al. method, which introduces a two-stage optimization model as a quick method way to choose the best potential links for implementing urban travel demand management (UTDM) strategies such as TOD [41]. In continuing the research, we present this paper to show what next if we want to modify land-use allocation.

Furthermore, few research types have been done on changing land use around selected stations to implement TODs through mathematical modeling and solving with metaheuristic algorithms. Therefore, this section has also attempted to investigate this research gap in the presented historical areas. This paper attempts to run a different approach by considering a different solution and method for finding the best land use modification around TOD station by considering ancient and historical areas' limitations.

3. Methodology

This section deals with selecting two target stations in ancient and historical places of Qazvin city to modify land-use arrangements. In the following methodology, this section describes genetic algorithms and introduces the mathematical optimization model's objectives.

3.1 How to Select Stations for TOD Implementation in Ancient and Historical Areas

In this study, due to the TOD mission in solving the traffic congestion problem, the Qazvin city transportation network links with a volume Capacity ratio close to 1 (V/C~1) were selected as candidate links for TOD implementation. These selections are based on applying the MHCCUE model from Zargari et al. research to Qazvin city[41]. Another complementary criterion is BRT lines and the tramway that their implementations in specific directions are predicted in the Qazvin transportation and traffic comprehensive plan. Therefore, in this study, to consider both criteria in Qazvin's ancient and historical areas, the conjoint points of these two criteria were selected for choosing the potential TOD locations. Moreover, by reviewing the literature concerning the essential rules in TOD implementation, three criteria of Density, Diversity, and Distance (3Ds) [42] have been considered for the candidate stations. Thus, for ranking the candidates, the AHP has been taken. In this regard, for a 300-m radius (the usual radius for TOD implementation in small-scale cities)[43] around the candidate stations adjacent to historical areas like Peighambarieh Mosque, Shazdeh Hosein Shrine, Amini house, Ali Qapu transom, Sepah Street, and its market, Qazvin bazaar, and ancient Mosque of Qazvin Jameh Mosque of Qazvin which is one of the oldest mosques in Iran based on the studies' results[44-48], density (population to area ratio), diversity (entropy index), and distance to intersection points of the BRT and tram lines were calculated. Then, to demonstrate the importance of each of these three criteria, the AHP questionnaire was designed, and 20 different experts in transportation and urban planning responded to it. The weight of the expert's opinions on the three criteria mentioned was multiplied by the values obtained for the selected stations to see the influence of the experts' views on the selection of proper stations. Then the AHP scoring method was used for co-scaling the obtained values. Points are added together. A station with three different criteria that reflect the station's final score was selected to implement TOD. A more consistent station with the TOD criteria and limitation was based on a historical context selected as the endpoint with a rated stations' field visit. Finally, the two stations 6 and 19 located in the streets of Shohada (the previous name was Sepah which was named the oldest street in Iran), and Imam Khomeini were selected as high-rank locations.

3.2 Genetic Algorithm

The Genetic algorithm is one of the more reliable metaheuristic algorithms for problem-solving based on a model of evolution[49]. Like any other optimization algorithm, the genetic algorithm defines the optimization variables, the cost function, and the cost. It ends like different optimization algorithms, too, by testing for convergence; a flow chart of the genetic algorithm's components is shown in Figure 1[50].

The improvements of the iterations are based on the simulation and the emergence of new productions from the previous generations' mixing to enrich the objective function's value.

- Chromosomes: In genetic algorithms, each chromosome represents a point in the search space, meaning a possible solution to the problem. The chromosomes are prepared by a fixed number of genes (variable). Binary encodings are usually used to represent chromosomes.
- Population: A set of chromosomes forming a population. With the influence of genetic operators on each population, a new population with the same number of chromosomes is created.
- Fit function: This function returns a nonnegative numeric for each chromosome, representing the individual's competence or ability.

Mutation operator: Mutation is a genetic science phenomenon that rarely occurs on some chromosomes, during which children find traits that do not belong to any parent[51].

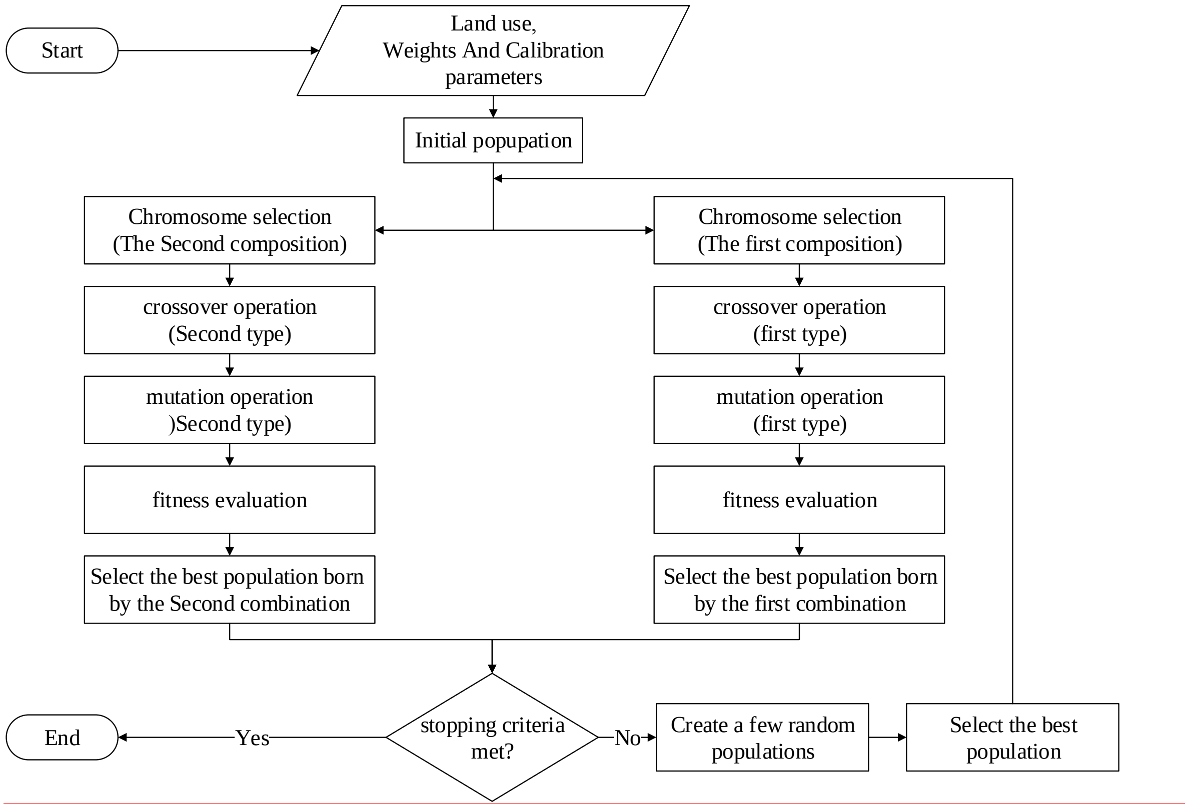


Fig 1. Flowchart of Genetic Algorithm

3.3 Developing the Mathematical Model for Land Use Modification at Selected Stations for TOD

After the optimized stations for TOD were selected, the arrangement of land uses around the obtained stations for TOD implementation will be examined by making a multi-objective mathematical model based on Sahu's research in 2018[30].

This model is defined as having a general cost function that includes four sub-objectives.

O_1 = Maximize the density of commercial, residential, and mixed land use

O_2 = Minimize the TOD skyline border to preserve the zone's historical identity

O_3 = Minimize the degree of land-use change

O_4 = Maximize the density of the land use allocation based on the TOD rules

$$f(O) = (W_1 \times f(O_1)) - (W_2 \times f(O_2)) - (W_3 \times f(O_3)) - (W_4 \times f(O_4)) \quad (1)$$

Where,

$f(O)$ = Objective function, W_i = Weight of ith objective, $f(O_i)$ = value of the ith objective

The values of W1, W2, W3, and W4 are assumed to be 0.2, 0.6, 0.1, and 0.1, respectively, according to the Sahu study in 2018[30]. The overall objective is defined above by multiplying the weight of each objective by its function. Each weight demonstrates the importance or the impact of each of the objectives on the primary objective function. Therefore, this model's overall objective is to maximize TOD Characteristics while minimizing the ideal skyline for TOD, minimizing the degree of land-use change, and increasing the density.

3.3.1 First Sub-Objective

Target functions to maximize the density of commercial, residential, and mixed land use are as follows[52]:

$$f(O_1) = W_1 \times C_1 + W_2 \times C_2 + W_3 \times C_3 \quad (1)$$

W_1, W_2, and W_3 = Weights from Table 1

C1, C2, and C3 = number of residential, commercial, and mixed land use in each station, respectively.

C1, C2, and C3 are changing around each station in each step of optimization. Shastry introduces the weight of characteristics for each of them, as shown in Table 1. These are proposed as a general rule[52].

Table 1

Weight of Shastry results for TOD characteristics

Characteristics	Weights
Housing density	0.372
Employment density	0.294
Mix use structures	0.333

The presented weights of Table 1 are just a suggestion for running the model. They could be changed based on the choice of decision-makers. Here in this section, we would mention that Hosseinali et al. present several methods to simulate the dynamics of land-use changes in Qazvin city, and their solution is based on agent-based modeling[53]. Thus, the value of characteristics weights could be even emerge based on the literature. Still, this paper is modeled based on the Sahu study's optimization method [30] to figure the best arrangement and make it possible for any comparisons.

3.3.2 Second Sub-Objective

This section outlines the importance of saving the skyline borders to keep the context of historical areas as much as possible. The Shaping the skyline objective for TOD execution is calculated as follows[30]:

$$Minimize\ f(O_2) = \sum_{i=1}^{n} \left| (den_r \times div_r) - \left(7386755.28 \times e^{-0.0054 \times dis}\right) \right| \quad (3)$$

$\mathrm{den_r}$ is Random value for density,
$\mathrm{div_r}$ is Random weighted diversity, dis is Euclidean distance of each user block to the selected station to execute the TOD, n is the number of blocks.

For example, station 19 was selected to execute the TOD; the parameters were calculated as follows:

$$Density = \frac{n \times 9.542 + m \times 4.771}{S} \quad (2)$$

n *is* Number of residential uses, m is Number of mixed uses, S is Station area = 282618

The average per capita population in residential units at Station No. 19 was calculated by dividing the people of the station (6966) by the number of residential uses (730) at the station (6966/730=9.542). The average per capita population per block is half of the residential one (9.542/2=4.771).

$$Diversity = \frac{log(a) \times a + log(b) \times b + log(c) \times c + log(d) \times d}{\ln(4)} \quad (3)$$

a is the percentage of residential use, b is the percentage of mixed land use, c is the percentage of commercial use, d is the percentage of public use

The distance, which is the Euclidean distance of each user block to the station, is calculated using ArcGIS. Since Qazvin city has a network of pedestrian streets connected to walkable cities like Porto[54], this objective is one of the main ones.

3.3.3 Third Sub-Objective

The third sub-objective is to minimize the changes in land use while implementing TOD. It helps to keep the context of land use as much as possible to preserve the regions' historical identity. Plans with minimum changes are more acceptable. To mathematically model, this sub-objective each of the lands uses is assigned a value given by Table 2.

Table 2

Degree of Change [30]

Checking the degree of change in land uses		Allotted land use			
		Residential (value = 0)	Mix use (value = 1)	Commercial (value = 2)	Public (value = 4)
Initial land use	Residential (value = 0)	0	1	2	4
	Commercial (value = 2)	2	1	0	2
Initial land use	Public (value = 4)	4	3	2	0
	Mix use (value = 1)	1	0	1	3

The objective function of this sub-objective calculates as follows[55]:

$$Minimize\quad f(O_3) = \sum_{i=1}^{n} |I_i - G_i| \quad (4)$$

where,

$f(O_3)$ = objective 3,

I_i =Initial land use of the block,

G_i = New allotted land use of the block,

n = Total number of blocks

Example: If a block has a Commercial land use (value = 2) and its use is transformed into residential land use (value = 0) the degree of change will be equal $f(O_3) = |2-0|=2$. The changes in land use should be as low as possible.

3.3.4 Fourth Sub-Objective

According to a study by Stewart et al., the number of neighbors per user block with the same user is defined as density[56]. Each block has eight neighbors (excluding the edge blocks, which have fewer). Using the values given to the land use in the previous objective, density can be calculated.

The number of neighbors of each block and their uses is calculated using ArcGIS. The following objective function is calculated mathematically to express this problem.

$$Minimize \quad f(O_4) = \sum_{i=1}^{n} \sum_{x=1}^{8} |C_i - N_{ix}| \qquad (7)$$

where,

$f(O_4)$ = objective 4,

C_i = Block I's land use value,

N_{ix} = Block I's neighbor x's land use value,

n = total number of blocks

3.4 How to Solve the Objective Function Using a Genetic Algorithm

We used the genetic algorithm (GA) to find the optimal value of the function ($f(o)$) in such a way that the value of 1000 parents is randomly generated and 50 of these values are selected, which gives us the maximum value in the fitness function. These 50 values are used to make the next generation. For the birth of the next generation, we proposed several different combinations. Among the proposed combination models, after a few runs, we found that the two types of combinations impact optimization. The first combination model works so that the two genes are randomly selected block by block. See Table 3, which is an example of a combination to understand this combination model type.

Table 3
Example of the first compound used for the mutation in user blocks

block id	The first gene	The second gene	New gene (new land user of the combination of two choices)
1000	0	0	Random (0,0)
1001	0	1	Random (0,1)
1002	1	3	Random (1,3)

Because the identified stations for the implementation of TOD in the city center are also ancient to historical areas, the public uses have not changed. They have remained constant (for example, block_id:1003). From the first type of combination model (50*50), 2500 new genes are obtained, and again from these genes, the 50 values that have the highest value in the fitness function are selected. This type of selection model has a top speed in increasing the fitness function's value, but it quickly stuck in the local minimum. To compensate for this in the first type combination model, we proposed the second type combination model, which has a lower speed in increasing the fitness function's value. Still, the probability of it stuck in the local minimum is very low and almost zero. The model selects the gene with the highest value of the fitness function in the previous step, and by changing only one of the blocks (randomly), the value of the fitness function is calculated. This change is made 800 times in each repetition of the generation (the number of blocks in each station is less than 800) so that almost every block changes its usage once, which gives us 800 genes, then we select the 50 genes that have the highest value of the fitness function. See Table 4, an example of this combination, to understand the second type of combination model. Then, for the next generation, 50 selections from the first model with 50 selections from the second model and 50 random genes are introduced to the next generation (to minimize the possibility of local minimum). This repetition of generations continues until the fitness function's value is the same for 50 consecutive generations. The best possible gene for land-use changes is plotted using Python output and inputs this information to ArcGIS. After solving each station's objective function, the initial usage of the best possible plans for stations 19 and 6 has been presented in the following figures (Figures 2, 3, and 4).

Table 4

The second compound is used for the mutation of user blocks

block id	The gene (user) with the highest amount of fitness function of the previous step	New gene (user) 1	New gene (user) …	New gene (user) 800
1000	1	Random (0,1,2)	…	1
1001	0	0	…	0
1002	2	2	...	Random (0,1,2)
1003	0	0	…	0

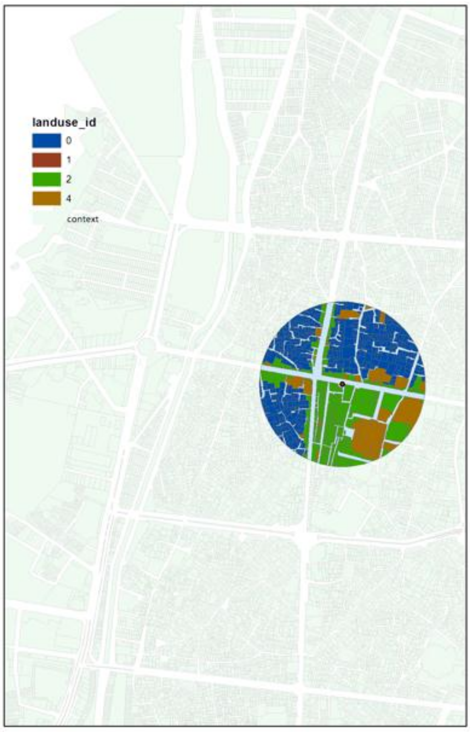
4. Results

As mentioned before; values were assigned to each land use (residential = 0, commercial = 2, mix = 1, public = 4). The result of a change in land use is also based on these values. Finally, Table 5 shows the percent change in the initial and final usage after each TOD run at each station. As it is visible in figures (2, and 3), with minimal damage to the historical context the usages' arrangement has changed after solving the objective function in a way that the mixed and commercial land uses are placed in closer proximity to the station, while residential and fewer density blocks are farther away. This is similar to the basic layout development focused on public transportation. Changes in the percentage of land use also indicate the same phenomenon. Figure 2 and Figure 3 show the map results within a radius of 300 m around the selected stations to implement TOD.

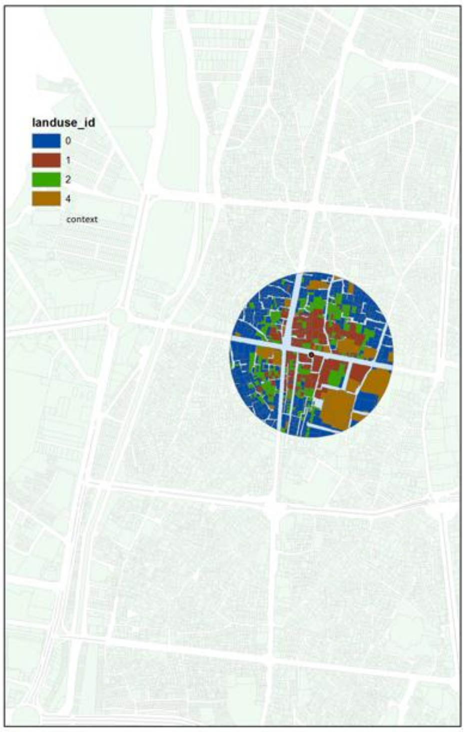
As expected, the percentage of residential and commercial uses had the most change. In station 6 the most change related to residential uses with a decrease of about 30% but at station 19 the most remarkable change related to commercial uses with a decrease of about 10%. Due to more commercial uses in Station 19, this station's most significant change is related to commercial uses. At both stations, we see that mix-use has increased dramatically and residential uses have decreased, which is in line with TOD principles. This increase in shopping centers and the mixed land-use resulting from the TOD implementation will help develop these historical centers with minimal damage. A balance can be struck between developing and preserving historical contexts by implementing this type of TOD and historical context development without damaging these sensitive contexts. Of course, this model's implementation depends on many other factors and issues, such as allocation. As the results show, using the genetic algorithm developed for this model, this method could get very close to the global monkey, which can be deduced from the logical order that conforms to the TOD criteria. Before implementing the TOD at Station 19, most commercial uses were limited to a specific area. The TOD implementation and the increase in mixed uses will allow the entire area to develop evenly. In Station 6, commercial land uses are distributed linearly, which changes radically with TOD implementation, which is in line with TOD principles. In this model, some commercial uses must be converted to residential applications, which is much more difficult and costly to change than residential to commercial and mixed-use. In this study, public uses were assumed to be constant, while TOD, by creating more jobs, would probably need more public uses in that area, but this change has been ignored in this study.

Table 5
Percentage of land-use change

Station No.	**Land Use**	**Initial Percentage of land uses <u>before</u> TOD implementation**	**The final percentage of land uses <u>after</u> TOD implementation**
6	Residential	80.64	51.36
	Commercial	11.96	19.64
	Mix use	0	21.88
	public	7.10	7.10
19	Residential	61.61	54.71
	Commercial	32.44	22.26
	Mix use	0	17.07
	public	5.93	5.93

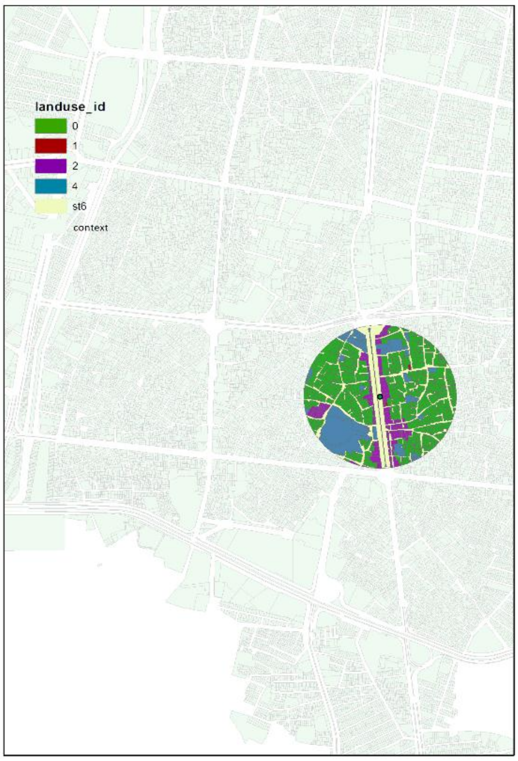


(a)

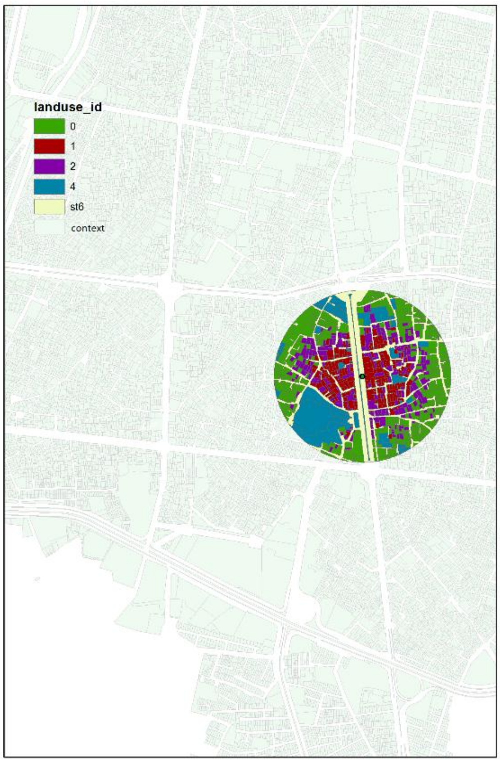


(b)

Fig. 2. The initial (a) and final (b) situations in Station No. 19



(a)



(b)

Fig. 3. The initial and final situation in Station No. 6

5. Summary And Conclusions

The rapid growth of cities and the subsequent dependence on cars has caused many problems such as traffic congestion, air pollution, and noise. Today, in most industrial and advanced countries globally, to solve the dilemma of urban and suburban traffic, the use of public transport has been advocated as the ideal solution, and most solutions incorporate increased usage of this system. TOD at any scale offers appropriate opportunities for dense and mix development and can be considered as an effective way to achieve an integrated model of land use patterns and transport planning around stations and determine the sustainable way of relocation in urban areas. However, TOD planning will lead to beneficiaries' participation and residents' continuous presence in the planning and decision-making process.

Moreover, public transport alone is not enough to solve urban traffic problems, and this system will work well when it is in sync with urban development and urban land use planning. Today, the approach solves this problem by making a mutual interaction between public transport development and land development. In this paper, considering the importance and necessity of identifying potential points for TOD implementation in ancient and historical land use and how to modify land use around selected stations in these areas, considering a multi-objective mathematical model with four objectives, maximizing per-capita job and household and mixed land uses as a percentage, minimizing deviation. The ideal skyline for TOD based on historical regulation limitations, minimizing the land-use change in the plan, provided the best possible plan for historical land use around selected stations to implement TOD. This mathematical model can help present TODs in Iranian or other developing countries with cities that have not yet implemented a scientific approach to this issue. The TOD plans' final form shows that mixed and commercial land uses are assigned closer to the station than residential, and as the distance from the station increases, the land uses become more residential.

The criteria for selecting public transport stations, such as the V/C ratio obtained from the network traffic assignment results, are this research's innovations. The calculation of TOD implementation criteria, including density, diversity, and distance, is quite different from other studies. In recent studies conducted in Iran, optimizing land use arrangements around selected stations for TOD implementation has not been considered. Therefore, this study's strength can be regarded as the study of land use arrangements in selected stations to implement TOD using an optimized mathematical model.

Reviewing the percentage of land use before and after the implementation of mathematical modeling for the best possible plan to implement the TOD in stations shows that the rate of mixed uses in both two stations increased while the commercial usage in station 19 increased and in contrast, at the 6th station, it decreased. This is due to a series of commercial land uses placed in a lower station center radius regarding historical area protection and land development constraints.

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