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A Decision Model for Railway Project and Development Density Using a Multi-objective Optimization Method

Ingon Ryu[a], Seungkyu Ryu[a], Yongju Yi[a]*, Keechoo Choi[b]

[a]*TOD-based Sustainable Urban/Transportation Research Center, Ajou University, Suwon, 16499, South Korea*
[b]*Department of Transportation Engineering, Ajou University, Suwon, 16499, South Korea*

Abstract

In South Korea where large-scale residential development and redevelopment are being carried forward continuously in various region, it is possible to increase social utility by making decision combined with railway transportation network and urban planning factors. This research proposes a mathematical model that simultaneously determines the development density, an urban planning factor, and the number of candidate railway projects. Specifically, by using bi-level model, the upper level produces the optimal solution of railway project and urban development residential population that can achieve the objective, while at the lower level, the combination of the traffic distribution of passenger – the modal split – route choice leads to equivalent route volume, the amount of trips classified by modes, and origin-destination trips at the same time. Lastly, analysis are performed to determine the effectiveness of model through the experimental network.

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Keywords: transit network design; goal programming; transit-oriented urban development; genetic algorithm; combined model

1. Background and purpose

Transportation planning and urban planning are decision making process affecting each other, but most transportation planning model assume urban planning situations (such as urban development location and planned population) as predetermined or probabilistic parameters and estimate travel demand. However, factors related to urban planning can be also determined by changed depending on the situation of transportation network. In particular, in the metropolitan area of Korea, as large-scale land development and redevelopment are being reviewed or promoted in various area, a model determined by linking them to each other will also be effective.

* Corresponding author. Tel.: +82-31-219-3604; fax: +82-31-219-3253
E-mail address: srzr2001@ajou.ac.kr

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On the other hand, the adverse effect of external effects such as traffic congestion in metropolitan area are emerging as an obstacle for sustainable development of the region. The Seoul metropolitan area has been pushing for a plan to construct a radial broad railway system centered on Seoul to solve these problems. In addition, transit oriented urban development has become an important policy alternative for the past years.

The Seoul Metropolitan Rapid Transit Railway, also known as Great Train Express (GTX), which began to discuss in 2008, has a longer interval and a higher scheduled speed than the existing metropolitan railway. Therefore, the competitive advantage is expected compared to other rail modes for the daily trips ever generated from the satellite city. However, the planned rapid transit railway has been proposed and evaluated based on the axis that meets the policy and simple engineering judgement rather than deciding the route and planning for the development of the connected area to meet the policy goals of the national and the metropolitan area.

Generally, the construction or priority of the transport infrastructure is determined based on the nature of individual projects rather than the combination of multiple, three-dimensional alternatives that can achieve policy objectives. Such an infrastructure input can lead to inefficient deployment of social resources, which can lead to confusion in the decision maker's goal setting and implementation process.

Land Use Transport Interactions (LUTI) have been studied in urban planning or geography, not in the area of transportation planning. However, the LUTI does not find optimal solution based on optimization model considering land use and transportation, but observing aspect change of dependent variables that affected by change of input variables.

In the situation of various candidate railway project and urban development project is existed, this study constructs transit network design problem and provides solving methodology. While applying goal programming, environmental, modal share and equity factors are used as an objective measurement to perform policy supporting. To develop solving algorithm, lexicographic goal programming is applied to find the optimal solution along with preference ranking of objective measurement. Finally, developed model is applied on the toy network to verify model structure and effectiveness.

2. Literature review

In the case of road network design problems, various studies have been carried out in recent years in which the equilibrium state of the network is considered in order to combine with urban planning elements. Yim et al. (2011) designed the bi-level problem to maximize the probability that all links would operate below a certain capacity. The sub-problem is designed for combined model with trip distribution and assignment, while higher problem is designed for maximizing network reliability index. Genetic algorithm is applied to decide optimum variables related to residential and employment. Li et al. (2014) proposed using a two-stage model to maximize total system utility and to optimize the location of residences and work sites of commuters. An and Lo (2015) suggested the problem of minimizing the sum of operation, construction, transit and transit costs of the express rail line and call taxi with consideration of relationship between the gravity model and the density in the model.

However, studies on transit network design and urban planning generally take place under the assumption that the amount of origin-destination trips is deterministic or stochastic (Ben-Tal et al., 2011; Wan and Lo, 2009), and only some studies consider the density of urban development, which is the basis of the origin-destination trips. In order to generate OD for each transit modes, Laporte et al. (2007) combined the problems of trip generation, trip distribution, and the modal spilt into railway network design. In the study of Quadripoglio and Li (2009) and Li and Quadripoglio (2010), the problem of feeder transit network design that finding critical population densities to reflect fixed and variable demand-based services. Samanta and Jha (2011) model railway lines for different objectives, such as maximizing the number of passengers or minimizing user costs. Lai and Schonfeld (2016) proposed a model to optimize the location, type, and layout of station, and used geographic information systems and genetic algorithms to solve problems.

The problem of transit network design differs in form and type in terms of decision variables, cost function, and solving algorithms in comparison with road network design problems. Therefore, the related research in the road sector has not been widely applied to the transit sector. Therefore, this study define a combined model to determine the transit network design variables and urban planning design variables and propose an algorithm to solve them.

Specifically, the decision variable is the development population density of the urban planning elements, and the relationship with the cost or demand between modes is implemented by applying the lower level of the bi-level model.

3. Multi-objective optimization model for determining railway project and development density

3.1. Model overview

The optimal railway project combination and population allocation ratio determination are performed in a way that finds the solution that best achieves the objective measurement by the decision maker under budget and cost constraints. In particular, the allocation of the population to the new railway origin-destination station or stopping region can increase the operational efficiency of the railway line, so that the railway project combination and the population allocation ratio will affect the transportation network at the same time.

Decision-making on the aspect of transportation and urban planning consists of a bi-level model in terms of suggesting an optimal strategy that reflects changes in passengers' travel behavior during the change of decision variables.

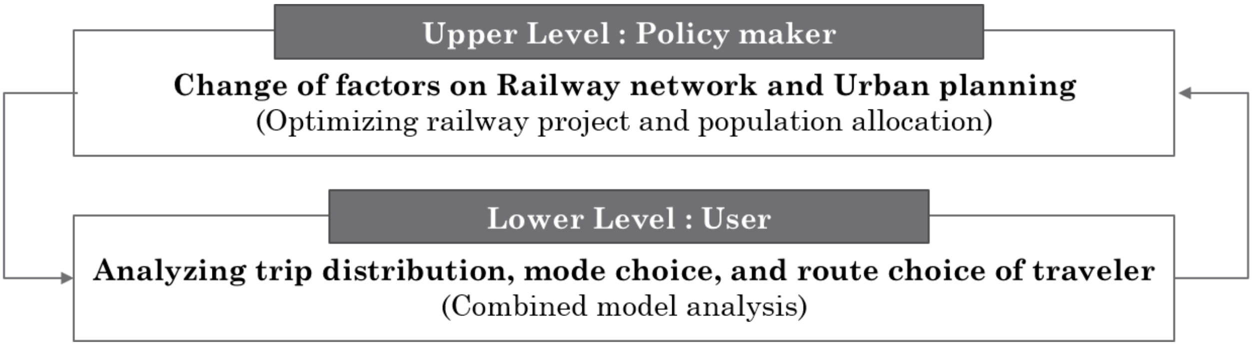

Fig. 1. Concept of bi-level model format

In constructing the objective function related to transit, it is necessary to consider the multiple objective functions at the same time for decision making. For this, the environmental, ratio of modal split and equity factors were set as the objective measure. In this case, a lexicographic goal programming method is used, in which various multiple functions with different units reflected at the same time and can take into consideration the priority among the target measures.

In particular, this study adopts the concept of genetic algorithm to find the optimal solution through the principle of evolution and finds the optimum new railway project and development density combination.

Specifically, in the integrated planning framework for railway and urban development, the decision maker should (1) establish the type of objective measurement, each target value, priority between objectives, and (2) budget agreement to be satisfied by the optimal new railway project. For these, the input and constraints of transportation and urban planning for each traffic zone are inputted as basic data.

After the baseline data is complete, an initial population of two variables is created. At this time, random chromosomes will be created to satisfy the budget constraints associated with the railway project, and population density associated urban development transport zones.

In order to introduce the variable demand concept, the combined model is applied based on the population combination ratio of each candidate chromosome in each initial chromosome, and the amount of travel demand by route, modes, and origin-destination are calculated. At this time, the combined model functions as a lower level of the bi-level model.

The deviation of each objective measure of the goal programming method could be calculated, and other objective measures than the environmental quality, measure share ratio, and equity can be added or substituted according to the interests of the decision maker. It is also possible to adjust the preferred priority between objective measures.

If the deviation of the objective measure does not satisfy the termination condition, the genetic operation is applied to update the solution of the railway project combination and the population density, and then iteration of the demand change model is performed through the combined model.

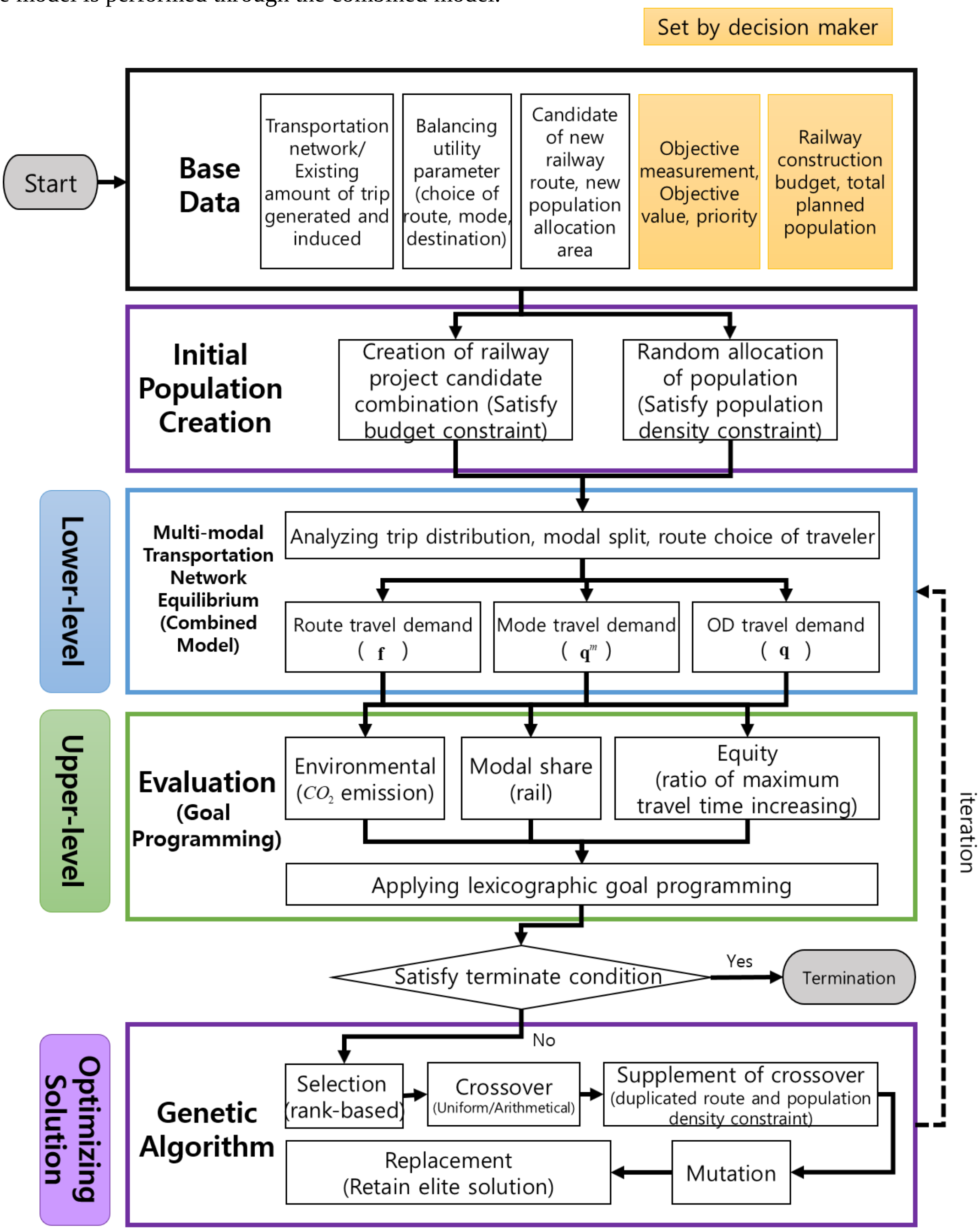

Fig. 2. Concept of model and flowchart of solution algorithm

3.2. Detailed model construction

3.2.1. Objective measurement

3.2.1.1. Environmental

Emissions related to the environment are very diverse. In order to achieve plan of the response to climate change in December 2016 in South Korea, we have set up a greenhouse gas emission as the main objective measure. The mathematical formula that reflects this is as follows.

$$F_1(\mathbf{x}, \mathbf{Y}) = \sum_{a \in A} EF_a(v_a(\mathbf{q}^m(\mathbf{x}, \mathbf{C}(\mathbf{Y})))) \times v_a(\mathbf{q}^m(\mathbf{x}, \mathbf{C}(\mathbf{Y}))) \tag{1}$$

Where $EF_a(v_a(\mathbf{q}(\mathbf{x},\mathbf{C}(\mathbf{Y}))))$ is the emission factor, which means the amount of carbon dioxide emitted from the link per unit vehicle at a specific speed situation. At this time, the concept of q ($\mathbf{q}^m$) changes depending on whether the railway project is selected (**Y**) along with the population allocation rate (**x**), which affects the volume(v_a) and speed of traffic.

Specific emission factors can be composed of various forms. In this study, the estimation formula of passenger cars (Korea Development Institute, 2013) is applied among vehicle emission factors.

$$EF_a(v_a(\mathbf{q}^m(\mathbf{x}, \mathbf{C}(\mathbf{Y})))) = 896.391 \times \left(60 \times \frac{L_a}{t_a(v_a(\mathbf{q}^m(\mathbf{x}, \mathbf{C}(\mathbf{Y}))))}\right)^{-0.5062} \tag{2}$$

Where is the carbon dioxide emission (g), L_a is the length (*km*) of the link, and $t_a((v_a(\mathbf{q}^m(\mathbf{x}, \mathbf{C}(\mathbf{Y}))))$ is the traffic time (min).

3.2.1.2. Modal split

The modal split ratio is a policy target widely used not only in transportation planning but also in urban planning. This is because it is an indicator that can manage the overall operation of the transportation system for a wider area, rather than congestion in a specific area or individual road unit. A high proportion of public transportation (railway) mode means that energy savings can be made in transporting the same passengers and efficient utilization of urban space is possible. Therefore, the sustainability of the region can be secured. The mathematical formula reflected in this study is defined and analyzed as the amount of demand using railways relative to the total demand as follows.

$$F_2(\mathbf{x}, \mathbf{Y}) = \frac{\sum_{rs \in RS} q_{rs}^R(\mathbf{x}, \mathbf{C}(\mathbf{Y}))}{\sum_{m \in M} \sum_{rs \in RS} q_{rs}^m(\mathbf{x}, \mathbf{C}(\mathbf{Y}))} \tag{3}$$

q^R_{rs} denotes the travel demand using the railway between origin-destination *rs*, q^m_{rs} denotes the travel demand using mode *m* between the *rs*. If the population allocation ratio of a specific origin is different, the influence on the traffic congestion differs because the roads used for each origin are different. The construction of a new railway project also affects the cost of using the transportation network.

3.2.1.3. Equity

In this study, the indicators presented in the Meng and Yang (2002) study, which first examined spatial equity in transportation network design problems, are used. Here, spatial equilibrium is the maximum value of the increase in travel time after project implementation.

$$F_3(\mathbf{x}, \mathbf{Y}) = \max_{a\in A}\left\{\frac{t_a(\mathbf{q}(\mathbf{x}, \mathbf{C}(\mathbf{Y})))}{t_a(\mathbf{q}^0)}\right\} \tag{4}$$

$t_a(\mathbf{q}(\mathbf{x}, \mathbf{C}(\mathbf{Y})))$, $t_a(\mathbf{q}^o)$ denote the time of the link after the project implementation and before the project implementation. The travel time is determined by the established travel demand q^o before the project. After the project, travel time will be changed by the ratio of population allocation **x** and the construction of railway **Y**, and the maximum value of the network will be minimized.

3.2.2. Bi-level model

3.2.2.1. Upper-level

The objective function of the mathematical model to be optimized consisted of the lexicographical goal programming method. Lexicographical goal programming problem is to optimize based on priorities. For example, in this study, after reaching a unique value that minimizes the deviation (d_1^+) of the first objective measure, it reaches a unique value that minimizes the deviation (d_2^-) of the second objective measure, and it reaches a unique value that minimizes the deviation(d_3^+) based on it.

- Objective function:

$$\text{lexmin}_{\mathbf{x},\mathbf{Y}}\,[d_1^+, d_2^-, d_3^+] \tag{5}$$

- Constraints:

$$\sum_{a\in A} EF_a(v_a(\mathbf{q}^m(\mathbf{x}, \mathbf{C}(\mathbf{Y})))) \times v_a(\mathbf{q}^m(\mathbf{x}, \mathbf{C}(\mathbf{Y}))) + d_1^- - d_1^+ = b_1 \tag{6}$$

$$\frac{\sum_{rs\in RS} q_{rs}^R(\mathbf{x}, \mathbf{C}(\mathbf{Y}))}{\sum_{m\in M}\sum_{rs\in RS} q_{rs}^m(\mathbf{x}, \mathbf{C}(\mathbf{Y}))} + d_2^- - d_2^+ = b_2 \tag{7}$$

$$\max_{a\in A}\left\{\frac{t_a(\mathbf{q}(\mathbf{x}, \mathbf{C}(\mathbf{Y})))}{t_a(\mathbf{q}^0)}\right\} + d_3^- - d_3^+ = b_3 \tag{8}$$

$$\sum_{a\in \bar{A}} (g_a \times Y_a) \le B \tag{9}$$

$$\sum_{n\in \bar{N}} (x_n \times TP) = TP \tag{10}$$

$$d_i^+ \ge 0,\ d_i^- \ge 0,\ i = 1, 2, 3 \tag{11}$$

$$x_n \in [0,1],\ \forall n \in \bar{N} \tag{12}$$

$$Y_a \in \{0,1\},\ \forall a \in \bar{A} \tag{13}$$

Where d_i is a deviation from the target value with respect to the objective measure. Equation (6) represents the first objective measure, which is the environmental constraint, and Equation (7) means the second measure, the modal share constraint. Finally, Equation (8) implies the equilibrium constraint, which is the final objective measure.

g_a is the cost when the link railway project is constructed. In this study, it is defined as a constant, but it can be defined as a function influenced by the length of the railway project or the speed. It is not actually counted as a cost if it is not selected even if there is a cost (g_a) for all links of the candidate railway project link set ($\bar{A}$). The value of the left side of equation (9) should be less than the total railway budget constraint (B).

Finally, both negative and positive deviations should be non-negative, and the population allocation ratio (x_n) should be in the range 0 to 1, and the decision variable whether to build a new rail project should be one of 0 or 1.

3.2.2.2. Lower-level

In this study, we apply the lower-level mathematical model using the combined model proposed by Oppenheim (1995). In this paper, we assume that the decision-making of the passenger has a top-down structure, so that the model is constructed through the conditional probability of stepwise utility under hierarchical structure.

- Objective function:

$$\begin{aligned}\min Z(\mathbf{f}, \mathbf{q}^m, \mathbf{q}) = & \sum_{m\in M}\sum_{a\in A}\int_0^{x_a^m} t_a^m(w)dw + \frac{1}{\theta_r}\sum_{m\in M}\sum_{rs\in RS}\sum_{k\in K_{rs}} f_{km}^{rs}(\ln f_{km}^{rs} - 1) \\ & + \frac{1}{\theta_t}\sum_{m\in M}\sum_{rs\in RS} q_{rs}^m(\ln q_{rs}^m - 1) + \frac{1}{\theta_o}\sum_{rs\in RS} q_{rs}(\ln q_{rs} - 1) \\ & - \sum_{m\in M}\sum_{rs\in RS} q_{rs}^m h_{rs}^m - \sum_{rs\in RS} q_{rs}h_{rs}\end{aligned} \tag{14}$$

- Constraints:

$$\sum_{s\in S} q_{rs} = P_r, \forall\, r \in R \tag{15}$$

$$\sum_{r\in R} q_{rs} = A_s, \forall\, s \in S \tag{16}$$

$$\sum_{m\in M} q_{rs}^m = q_{rs}, \forall\, rs \in RS \tag{17}$$

$$\sum_{k\in K_{rs}} f_{km}^{rs} = q_{rs}^m, \forall\, rs \in RS, m \in M \tag{18}$$

$$x_a^m = \sum_{m\in M}\sum_{rs\in RS}\sum_{k\in K_{rs}} f_{km}^{rs}\delta_{km}^{rs}, \forall\, a \in A, m \in M \tag{19}$$

$$f_{km}^{rs} \geq 0, \forall\, k \in K_{rs}^m, rs \in RS, m \in M \tag{20}$$

$$q_{rs}^m \geq 0, \forall\, rs \in RS, m \in M \tag{21}$$

- Parameter definition:

$$\frac{1}{\theta_t} = \frac{1}{\theta_m} - \frac{1}{\theta_r} \tag{22}$$

$$\frac{1}{\theta_o} = \frac{1}{\theta_d} - \frac{1}{\theta_m} \tag{23}$$

In this study, objective function is to find the traffic volume f, travel mode demand q^m, and travel demand q which can minimize the mathematical equation of the combined model. The first term of the objective function is the Beckmann equation, which is generally applied to the user equilibrium problem where congestion effects are considered. The second, third, and fourth terms are entropy terms that correspond to the stages of hierarchy in making decisions related to traffic.

t^m_a denotes travel time function of link *a* related to mode *m*, f^{rs}_{km} denotes traffic volume using mode *m*, route *k* between origin-destination *rs*, q^m_{rs} means the traffic volume of the mode *m* between the origin-destination *rs*. q_{rs} means the traffic volume between origin-destination *rs*.

θ_r, θ_m, and θ_d denote route, mode, and destination parameters, respectively, and are related to the parameters of the objective function in the form of equations (22) and (23). This combined model constitutes an equality model based on utility. In this case, the attractiveness (h_{rs}, h^m_{rs}) can be regarded as a parameter related to the variation of the probabilistic utility which cannot be explained by the deterministic utility such as the travel time or the travel cost. Specifically, h_{rs} is the attractiveness of the origin-destination *rs*, h^m_{rs} means the attractiveness when the origin-destination *rs* is used as mode *m*. This attractiveness means exogenous utility, not income or travel time costs.

δ^{rs}_{km} is a link-route incidence indicator, 1 if the link *a* exists on route *k* between origin-destination *rs*, 0 otherwise.

Equation (15) ~ (18) mean the travel demand or traffic volume conservation condition. Equations (20) and (21) are non-negative constraints.

At this time, the transportation network ($G(N,A)$) differs according to whether the upper level railway project is selected (Y_a), and the amount of travel demand between origin-destination varies depending on the planning population allocation ratio (x_n).

3.2.3. Solution algorithm

The proposed bi-level model is inherently non-convex because it has a mixture of the decision variables of the railway candidate project and the allocation ratio of development density. Therefore, it is very difficult to solve the global optimization problem (Friesz et al., 1990).

In public transportation network design problem, it is possible to express various problems, reduce the operation cost by heuristic methodology which is easy to reflect discrete decision variables, objective function and constraint nonlinearity, and existence of conditional statement. Therefore, in this study, heuristic methodology, genetic algorithm is applied to approach the problem.

3.2.3.1. Chromosome expression

This study utilizes location-based representation. In other words, the first candidate project is fixed and the rail project variable is allocated to the binary system. Population allocations were also applied as a method of matching the population allocation ratios to fixed locations as a form of development candidate origin.

Chromosome #	Selection of railway project (binary)						Allocation of urban development population(real)				
	Candidate 1	Candidate 2	Candidate 3	…	Candidate 7	Candidate 8	Candidate 1	Candidate 2	Candidate 3	Candidate 4	Candidate 5
C1	1	0	0	…	0	1	0.10	0.19	0.16	0.27	0.28
C2	0	1	1	…	0	1	0.34	0.35	0.06	0.07	0.18
C3	1	1	0	…	1	0	0.03	0.20	0.24	0.21	0.32
C4	0	0	1	…	1	1	0.21	0.03	0.27	0.23	0.26
C5	1	0	1	…	0	0	0.14	0.27	0.19	0.13	0.27
C6	0	1	0	…	0	0	0.19	0.33	0.18	0.15	0.15

Fig. 3. Example of Chromosome and gene expression

3.2.3.2. Genetic calculation

If the multi objective function is converted into a weighted single objective function value, it can be applied to the weighted strategy to calculate the fitness and use it as the input value of the selection operation. However, in this study, the fitness evaluation and selection calculation methodology applying the ranking strategy is applied so that the lexicography goal programming method can be applied directly. The ranking strategy is to align the chromosomes from the best dominance to the most recessive gene, and assign a choice probability for each chromosome based on this order.

At this time, the process of adjusting the order of chromosomes (relative to the degree of dominance or recessive) is performed so that the preference structure of the objective measure can be reflected. This is the concept of ranking the chromosomes based on the first objective until the most preferred measure is achieved. After the first objective is achieved (or no further improvement), the chromosomes are ranked according to the second goal. This will allow the decision maker to find a solution in the order of preference measures defined.

In crossover operation, there are two constraints that the total project cost of the new railway project set should be smaller than the budget and the sum of the urban development population allocation ratio should be 1. It is also possible to derive the solution of the unfeasible region in the process of crossover or mutation calculation. Therefore, we applied the mathematical technique to the solution which does not satisfy the constraint condition in the genetic algorithm, and completed the crossover operation. when the implementation of projects exceeding the budget limit can be selected, and the constraint is satisfied by excluding some projects randomly until the total project cost of the selected project satisfies the budget constraint.

The mutation operation is divided into the railway project selection and the allocation. Random numbers were generated for each gene, and the mutation operation was applied in such a way as to change the project that was not selected or selected randomly, and to increase the population density

The replacement operation is applied to the regular sampling method. In other words, the best solution of the existing parent solution would not be replaced, and the algorithm was applied so that all the remaining child chromosomes could be selected to form the next generation population.

4. Case study

4.1. Simple network experiment

4.1.1. Analysis outline

For the convergence analysis of the model, we used 7 nodes, 13 links, and 5 origin-destination. Here, the BPR function is applied to the volume delay function of the road, and it is assumed that the travel time of the railway is not affected by the traffic demand. As shown in the yellow line in Figure 4, there are three links for the new railway projects candidates (link numbers 11, 12, and 13), and the population allocation candidates are assumed to be origin 1 and 3.

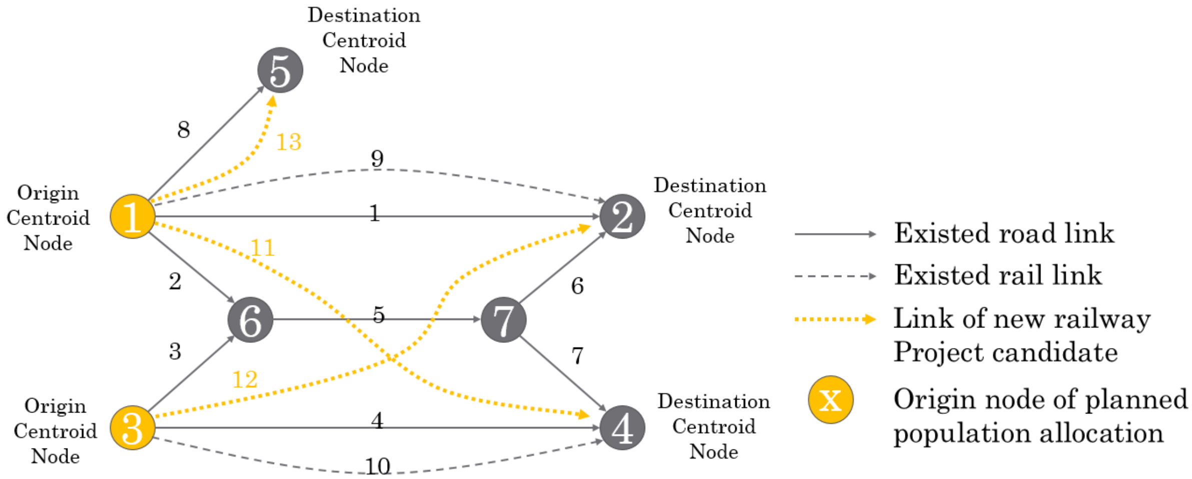

Fig. 4. Simple network

The BPR function parameter α and β are applied as 0.15 and 4.0, respectively, and the new railway candidate (link 11, 12)' travel time is assumed to be the same (10 minutes) as that of the existing railway link. The new railway candidate (link 13)' travel time is assumed to be 5 minutes. The free travel time for each link was assumed in consideration of the link length and the actual traveling speed of the urban area (about 20 km/h).

In order to find a solution under the budget constraint, it is necessary to know the project expenses for the individual project of the new railway. In this experiment, the project costs of new railway links 11 and 12 are assumed to be 5 billion KRW and the cost of link 13 is assumed to be 2 billion KRW. The total budget constraint is 10 billion KRW.

The combined model applied in this study can only reflect the amount of traffic as an input value because the traffic distribution, mode sharing, and traffic allocation are performed simultaneously when the amount of traffic and the amount of inflow are known.

The combined model applied in this study requires only travel demand production and attraction as input values. This is because the trip distribution, mode choice, route choice can be carried out simultaneously when the travel demand at OD pair are known. It is assumed that production at node 1 and 3 is assumed to be 100 trips, and the attraction at node 2, 4, and 5 are assumed to be 70, 70, and 60 trips, respectively. In addition, the total planned population for urban development is assumed to be 40 people. Here, the population allocation ratio by the development candidate sites (node 1 and 3) is a determining variable to be sought. However, node 2, 4, and 5 allocate attraction trip according to the proportion of existing attraction trip.

The experimental network is a small-scale network that performs path-based traffic assignment with all alternative routes connecting origin-destination pairs as decision variables. Since there are not many combinations of the new railway project, the number of gene population is set as 4. The crossover threshold is fixed to 0.3, and the mutation threshold is fixed to 0.1, population allocation's mutation threshold was set to 0.5 as parameters of the genetic operation.

Depending on the parameters of the destination choice, the mode choice, and the route choice may be somewhat different. The route parameter is set to 0.2, the mode parameter to 0.1, and the destination parameter to 0.05. The attractiveness h_{rs} and h^{m}_{rs} are assumed to have the same effect on the expected utility by applying zero.

4.1.2. Analysis results

Lexicographical expression as the goal programming method is applied, convergence starts with the highest environmental preference. After the first objective measure achieves the goal, the process of improving the solution is progressed in the order of the modal split and equity.

Since there is randomness in the generation of the initial solution of all the algorithms and the computation of the crossover and the mutation, the shape of the convergence curve can be somewhat different when it is repeated under the same conditions. In the convergence process shown in Fig. 5, The environmental measurement deviation was 0.1898 in the first generation, but continued to decrease it to zero in the 31st generation. The deviation of the modal split is 0.0005, and the equity deviation is 0.0275. Then, the process of decreasing the deviation of the modal split is continued, so that the deviation of the modal split becomes zero at the 50th generation, and the deviation of the equity at this time is 0.0229. Then, the process of reducing the deviation of the equity is continued, and the deviation of the equity is decreased to 0.0161 in the 100th generation.

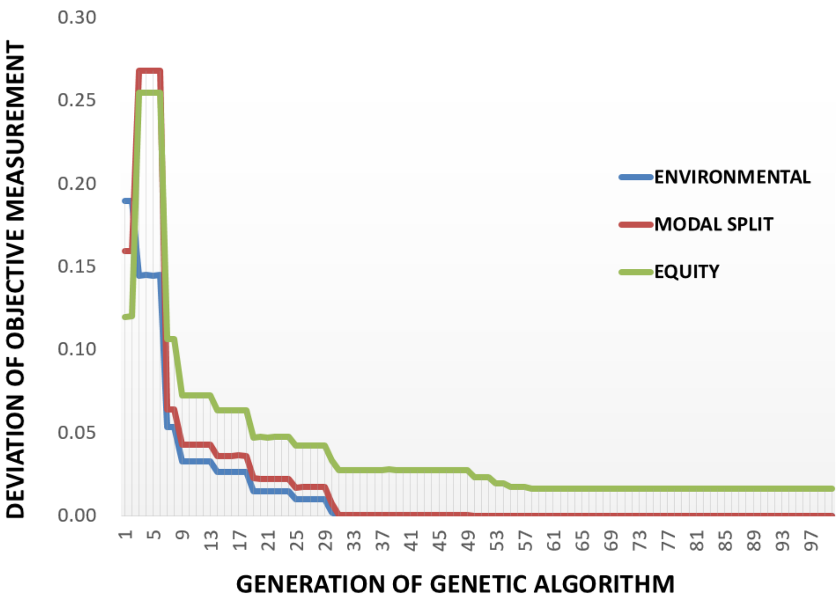

Fig. 5. Deviation convergence curve by objection measurement

The selected projects (link) is 12 and 13, and the optimal chromosomes were obtained by assigning 10.35% to origin node 1 and 89.65% to origin node 3. Emissions of the objective of the environmental objective were 78,753g, the mode share ratio was 43.69%, and the equity index was 1.0161.

The target for CO_2 emissions was 80,000g, and the goal for the modal share rate was 43%, which means that the two objective measures were achieved. However, the target for equity was 1.0, which was not achieved, and the deviation was 0.0161.

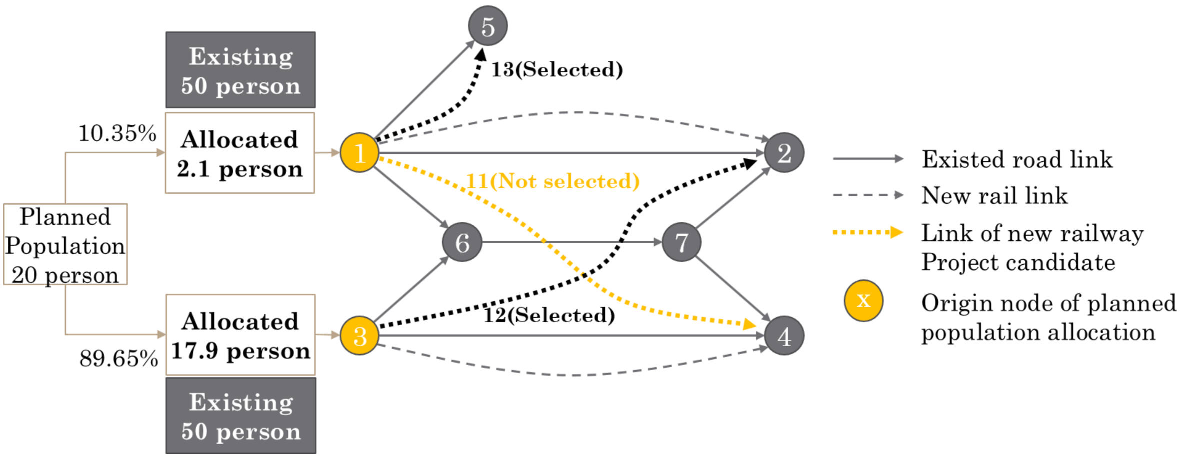

Fig. 6. Schematized optimal solution of simple network

If the new railway candidates do not exist and only the planned population is added, the first objective measure, CO_2 emissions, will not be reduced. However, as a new railway is built under the budget of 10 billion won, the CO_2 emissions decreased 18,342g (18.89%) from the existing 97,095g to 78,753g. The share of the mode of the railway increased by 26.66% from the existing 17.03% to 43.69%. Since minimizing CO_2 emissions on the road is the first and most important goal, both VHT and VKT on the road have been reduced in the implementation of the project, and VHT and VKT on the rail have increased.

Table 1. Simple network objective measurement and transportation index transition.

		Not implemented	Implemented	Difference	Note
CO_2 emissions (g)		97,095	78,753	-18,342	Budget constraint: 10 billion KRW
Modal share (%)		17.03	43.69	26.66	
VHT	Road	23.98	18.75	-5.23	Budget required: 7 billion KRW
	Rail	5.67	14.6	8.93	
VKT	Road	510.11	430.82	-79.29	
	rail	136.16	418.55	282.39	

4.2. Sketch-planning network experiment

4.2.1. Analysis outline

Road and railway transportation network are constructed with consideration of Seoul metropolitan area in Korea. 24 nodes, 76 existing road links, 26 railway links (assuming 3 metropolitan area express railway lines exist), and 8 new railway candidate links; total of 114 links are assumed. Eight traffic zones were assumed and analyzed. At this time, the road capacity and speed were analyzed under five VDF systems, and high capacity and free passage speeds were applied to the roads conceptualized as the Gyeongbu Expressway and the Outer Circulation Expressway.

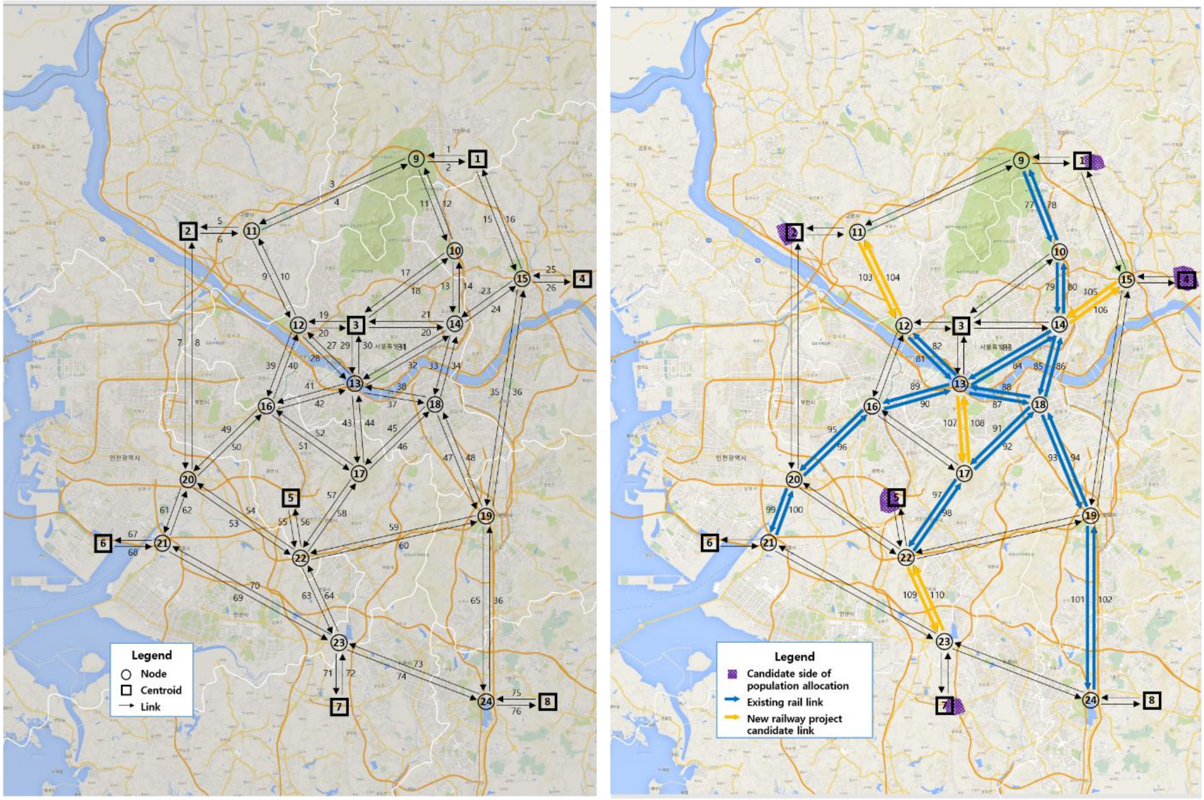

Fig. 7. Sketch-planning network

The travel time of the new railway candidate project is calculated assuming the speed 100 km/h. In addition, to find a solution under budget constraints, it is assumed that the project cost of 50 billion KRW per 1 km. The new railway links 103 and 104 are supposed to be one set of project that can handle bi-directional, and it is assumed that 750 billion KRW will be spent to construct a total extension of 15 km. The rest of the new railway links are 10 km, it costs 500 billion KRW. The budget constraint is 1.5 trillion KRW.

Each origin node is assumed to have 100,000 or 200,000 production trip per origin, and each destination node's attraction is assumed to be the same. In addition, the total planned population for urban development is assumed to be 1 million, and the priority structure is set in the order of environment, modal share, and equity.

4.2.2. Analysis results

The goal for CO_2 emissions was 7,000 tons and the target for the instrumental share was 40%, achieving both objective measures. However, the results were not satisfied with the goal of equity. Despite the new railway project, the increase of travel time on some links has been accompanied by the population increase.

Considering the budget constraint of 1.5 trillion KRW, the railway links of 103, 104, 109 and 110 were selected as the optimal projects (1,250 billion KRW for the project costs). At this time, 92.6% of the population allocation rate was allocated to the origin node 1 and 7, which had a sufficient capacity of the adjacent roads. Therefore, considering the 9 km^2 area of development site, the population of approximately 500,000 people was allocated to the origin node 1, the optimal population density was 55,566 (persons/km^2), and the origin node 7 was allocated the population of 425,000 and the optimal population density was 47,316 (persons/km^2) are required.

Table 2. Optimal planned population and population density on the sketch-planning network.

	Region 1	Region 2	Region 4	Region 5	Region 7
Ratio of population allocation (%)	50.01	0.69	6.34	0.38	42.58
Planned population (persons)	500,093	6,877	63,429	3,755	425,847
Population density (persons/km^2)	55,566	764	7,048	417	47,316

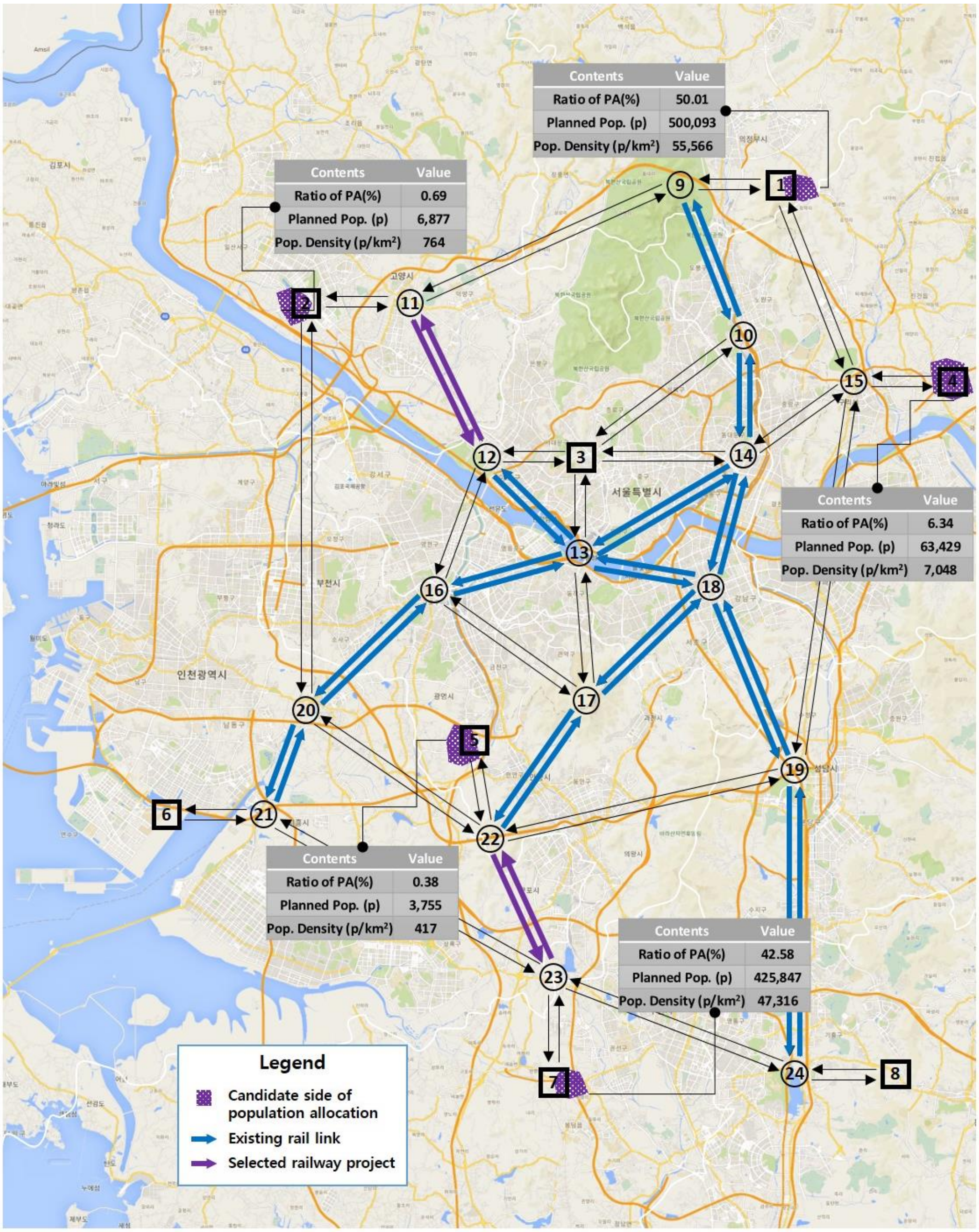

Fig. 8. Schematized optimal solution of sketch-planning network

5. Conclusions

This study proposes a mathematical model that simultaneously determines the development density and the number of candidate railway projects. The goal-based multi-objective function was applied to the optimization function of the mathematical model and the genetic algorithm was applied to solve the problem. To overcome the problems of existing genetic algorithms, a new algorithm considering integer and real variables is applied. Finally, this study applies the proposed model using experimental network.

In order to reflect various societal requirements in the policy decision process of transportation and urban planning, it is necessary to study the economic objective such as revitalization of the local economy and employment inducement, study of the target value or weight setting that can be recommended to the decision maker. In addition, since the combined model applied in this study is not examined or experimented on various aspects in Korea 's traffic network, it is necessary to carry out studies to improve the convergence efficiency in terms of experiments and algorithms to improve the reality modeling ability of the combined model.

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