

SPATIAL URBAN LAND USE PLANNING USING MULTI-OBJECTIVE OPTIMIZATION AND GENETIC ALGORITHM

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Abstract

Urban planning requires not only estimating and locating the future urban extent but also balancing planning aspects to achieve objectives and comply with constraints. The better planning should be able to compromise the multiple conflicting demands from different aspects. The aim of this study focuses on developing and simulating a procedure for optimal urban class planning using Genetic algorithm and Multi-objectives decision analysis (GA-MODA) in plot level. Resulting plans of 2016 were compared to existing land use. The methods were employed to operate on 2 case areas which were selected from a part of Nakhon Ratchasima town. GA-MODA process was applied to generating a number of representative plans that meet the requirement of 6 given objectives and 7 constraints. The objectives cover sufficient housing, employment, open green area, high compatibility, and minimized changing cost and travel rate. For better living, constraints were setup to comply with suggested areas and population densities of urban classes. GA-MODA process resulted in 26 and 370 plans for case areas. These plans were compared to existing land use. The comparison revealed that constraint compliance, being at Pareto front, and sums of normalized objective values (SNOV) of GA-MODA plans are better than of existing land use. It indicates that GA-MODA urban planning is a capable method to generate a number of optimal plans which can provide a better quality of living than existing land use.

Keywords: Key physical characteristics' factors, freight transportation routing, Delphi method, fuzzy analytic hierarchy process

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Introduction

Due to the increasing population and economic growth, human activities have continuous impacts on land use. The impacts might lead to series of complexities toward environment and land resources planning and development (Huang and Xia, 2001). Land use planning, one of the important development activities, is primary required according to the growth impact. It can be defined as the process of allocating different activities or uses to specific units of land within a region (Stewart *et al.*, 2004). Thus, urban land use change and planning have become ever-increasingly complex as a consequence of the growth. Obviously, many green spaces have been transformed into urban land use, e.g. residential, industrial, and commercial use. The planning requires not only estimating and locating the future urban extent but also balancing aspects that should provide both changing area and indicating the proper class to serve each individual policy.

From the past, there were a few researches serving the mentioned purpose.

This has to compromise the multiple conflicting demands from different groups of stakeholders such as government, merchants, and residents. Urban planning has become a multi-objective problem. Increased inclusion of objectives leads to different demands on the expected results (Stewart *et al.*, 2004). To serve the purpose, researches have been used multi-objective optimization Genetic Algorithm (GA) for urban planning to solve multi-aspect policy through multi-objective functions (Huang and Zhang, 2014; Zhang, 2014).

Many problems of demand conflict in the past could be handled using linear programming (LP) approaches (Guldmann, 1979; Aerts *et al.*, 2003). The LP model was first applied in the 1960s to solve problems in urban planning systems through linear or quadratic equations. However, the LP model cannot handle nonlinear and unstructured requirements like spatial interactions between land use types, it is not suitable for complex urban problems. Within this context, a heuristic algorithm, the GA, which is capable

of handling the unstructured urban issues, was proposed in the 1970s. Many researchers have applied a GA to solve multi-objective land use planning problems and some meaningful outcomes have been achieved (Huang and Zhang, 2014). For example, Cao *et al.* (2011) chose Tongzhou New Town, China, to demonstrate how GA for multi-objective optimization could be employed to meet three conflicting objectives based on minimizing conversion costs, maximizing accessibility, and maximizing compatibilities between land uses. Huang and Zhang (2014) developed a multi-objective optimization approach to finding sustainable land use planning for a downtown lake area in central China.

In Thailand, the urban planning has been operated on blocks or zones which consist of few or many individual plots. Currently under Thailand's National Economic and Social Development Plan, Nakhon Ratchasima represents a new growth secondary city which is one of the largest metropolitan populations for a city disconnected from Bangkok. Initially, its community settlements were confined to be within the old city limits with many constraints to growth (Cherdchai and Mayor, 2001). The surrounding area of the old city becomes high potential for urban growth and recently end up to be many times increasing of population and urban area. The subjected growth area is composed of many classes for social service, industrial, cultural, residential, and originally agricultural. Parts of the municipality can be either lower or overpopulated. Urban planning or proper class assignment in the plot level is required to moderate over and underpopulated problems by applying suggested areas and population densities to urban classes.

The aim of this research is therefore focused on developing a procedure and applying it to optimal urban class planning in individual plot level using Genetic algorithm and Multi-objectives decision analysis (GA-MODA) to solve housing and employment problems including open green area requirement so as to promote better quality of

life. GA was focused on generating the population of urban plans in 2016 for fitness test. MODA was applied to fitness evaluation under given objectives and constraints. Objectives cover sufficient housing, employment, open green area, high compatibility, and minimized changing cost and travel rate. For better living, the developed procedure includes constraints setup to flexibly comply with 2 suggestions, i.e. 1) suggested areas and population densities to urban classes and 2) suggested population densities for actual urban class areas. The suggestions were referred to the research particularly carried out for the study area. The purpose of this planning does not include infrastructure development, hazard and disaster zoning, and mitigation. To confirm that the developed procedure for urban planning is better than existing growth, urban plans achieved from GA-MODA were compared to the actual urban land use of the same year.

Data Collection and Preparation

Data of the study area required for the research cover attributes of multi-objectives and constraints employed in the GA-MODA process. The study area and relevant attributes were described and prepared as follows.

Study Area

The study area of this research is a part of Muang Nakhon Ratchasima comprehensive planning area and located in the southeastern corner. This area is sub center of Central Business District (CBD) growth from Muang Nakhon Ratchasima municipality. Currently, this area has high growth expansion tendency of communities, commercial, malls, governmental institutions, and industrial areas. The 2 case areas (Figure 1) were selected to confirm that the procedure developed for urban planning was flexible for possible cases and to test that all components of the procedure work properly. These components are composed of the code of GA process, objective functions, constraints, and dominance ranking or fitness procedure.

Urban plots of 2013 and 2016

Urban plots were required as input for the GA-MODA process to generate optimum urban plans. Urban plots in the study area of 2013 and 2016 were extracted by visual interpretation from QuickBird and WorldView data collected through Google Earth under the same interpreted scale (1:4,000). Urban plots of 2013 were used as a guide for 2016 interpretation and for changing cost evaluation. The urban land use was interpreted based on the modified classification of the Department of Public Works and Town & Country Planning (DPT) (2006) to be 16 classes (Figure 1).

There are various classifications of urban land use applied to different countries. They might be different from country to country based on geography and lifestyles. DPT (2006) classify urban land use totally into 22 classes. A set of classes from town to town can be different. For example, urban land use of Nakhon Ratchasima Municipality city covers 11 classes. To serve the purpose of the study that allows pragmatic transformation of

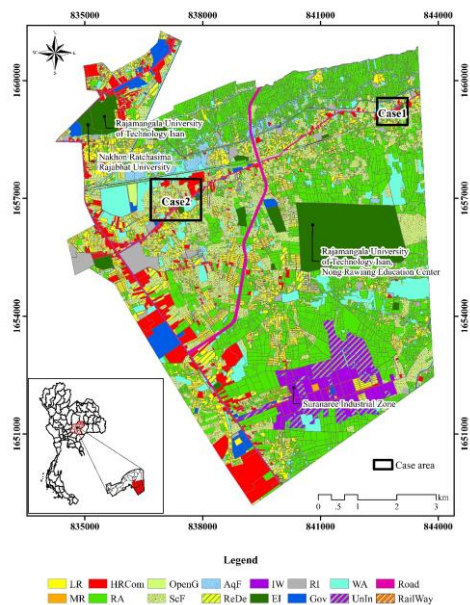


Figure 1. Study case areas in 2016 land use map of Nakhon Ratchasima town

classes, urban land use of the study area was modified to be 16 classes (with specific urban class ID used in GA-MODA analysis) i.e. ID.1, low residential (LR), ID.2, medium residential (MR), ID.3, commercial and high residential (HRCOM), ID.4, rural and agricultural (RA), ID.5, open land for recreation and environmental quality maintenance (OpenG), ID.6, scrub and forest (ScF), ID.7, aqua farming (AqF), ID.8, area ready to develop (ReDe), ID.9, industrial and warehouse (IW), ID.10, educational institution (EI), ID.11, religious institution (RI), ID.12, governmental institution, public utility and facilities (Gov), ID.13, water or wetland (WA), ID.14, undeveloped industrial (UnIn), ID.15, railway, and ID.16, road network. These classes will reflect on compatibility and changing cost matrixes of class transformation.

Suggested Population Density and Class Area As Constraints

According to the study of Phisut Technology Co., Ltd. and P&C Management Co., Ltd. (PST and P&C Mgt Co., Ltd.) (2010), under the supervision of Nakhon Ratchasima City Municipality, for better quality of living and efficient local administration the study suggested the proper percentage of class areas

and population densities in living and employment classes. Classes 1, 2, and 3 are directly concerned to housing capacity while classes 3 and 4 are for employment capacity. Rural and agricultural class is considered having very low living and employment rates. It is more likely and easier to be an area changeable to other classes. Population densities of classes i.e. open green area, educational institution, religious institution, and governmental institution were estimated from existing information in 2016 and field investigation to obtain base densities. Proper rate of these class areas are suggested by PST and P&C Mgt Co., Ltd. (2010).

For better quality of living, the proper percentage of class areas and population densities in living and employment classes were adopted from the study of PST and P&C Mgt Co., Ltd. (2010) as listed in Table 1. Field investigation for classes of OpenG, EI, RI, and Gov were added to fulfill the list. Information in Table 1 was further applied as constraints of objectives and to travel opportunity estimate.

Neighborhood plots and their compatibility

Neighborhood plot can be identified using Generate Spatial Weights Matrix function of ESRI® ArcGIS™. For a given

Table 1. Modified urban land use class and parameters of relevant MODA objectives

No.	Urban land use class	Population density (persons/rai)	Suggested area (%)	Preserved class	Obj.1	Obj.2	Obj.3	Obj.4	Obj.5	Obj.6
1	LR	3	34.09	-	C	-	-	✓	✓	✓
2	MR	10	10.03	-	C	-	-	✓	✓	✓
3	HRCOM	15	4.08	-	C	C	-	✓	✓	✓
4	RA	0.5	36.51	-	-	C	-	✓	✓	✓
5	OpenG	<u>2</u>	4.95	✓	-	-	C	✓	✓	✓
6	ScF	-	-	-	-	-	-	✓	✓	✓
7	AqF	-	-	-	-	-	-	✓	✓	✓
8	ReDe	-	-	-	-	-	-	✓	✓	✓
9	IW	10	3.20	✓	-	-	-	✓	✓	✓
10	EI	<u>0.8</u>	2.06	✓	-	-	-	✓	✓	✓
11	RI	<u>1</u>	0.62	✓	-	-	-	✓	✓	✓
12	Gov	<u>2.5</u>	2.06	✓	-	-	-	✓	✓	✓
13	WA	-	-	✓	-	-	-	-	-	-
14	UnIn	-	-	✓	-	-	-	✓	✓	✓

Note: C : information of a class works as objective constraint(s),
 ✓ : a class relevant to objective,
 xx : investigation to obtain base densities,
 - : a class non-relevant to objective.

plot, the function provides IDs and a number of neighboring plots. The reciprocal of a number of neighboring plots work as weights and incorporates with the level of compatibility and plot areas when compatibility value of each plot is estimated in the Objective 4. Compatibility is considered between classes of a plot and its neighboring plots. DPT (2006) introduced the levels of compatibility to be high, moderate, and incompatible in the matrix of classes. To be able to estimate objective value, compatibility levels in the matrix were transformed to be 1, 0.5, and 0, respectively (Table 2).

Changing Cost Matrix

In the urban growth process, when a class of plot was transformed to be another class, the difficulty of change was considered in a scale of 0 to 1 of changing cost (Zhang, 2014). The higher value indicates higher difficulty. In this study, some given classes were considered unchangeable and should be preserved. They are educational institution areas, religious

institution areas, open green areas. In specific cases, some certain classes are not allowed to change backward to be less developed classes. HRCom cannot change to be any classes. MR can change to be only HRCom. LR can change to be only MR and HRCom.

The cost of class changing matrix was obtained from the survey of expert opinions through semi-interview and questionnaire. Ten experts included staffs of DPT of Nakhon Ratchasima and urban planning management lecturers. The class changing cost matrix is displayed in Table 2. The changing costs were normalized to be 0 to 1. The values interval from the expert was 0.18 to 0.77.

Road Impedance and Optimum Paths

Optimum paths between origins and destinations (O-D) were obtained by network analysis. Every plot in a plan could be both origin and destination. A set of these paths was considered the same and could be applied to every plan in the GA process. The impedance of every path together with travel opportunity

Table 2. Matrix of compatibility scores (in parenthesis) and class changing cost

No.	Land use class	LR	MR	HRCom	RA	OpenG	ScF	AqF	ReDe	IW	EI	RI	Gov	WA	UnIn
1	LR	(1)	0.18	0.35	**	**	**	**	**						
2	MR	**	(1)	0.24	**	**	**	**	**						
3	HRCom	(1) **	**	(1)	**	**	**	**	**						
4	RA	0.25 (0.5)	0.35 (0.5)	0.55 (0)	(1)	0.28	0.54	0.41	0.42						
5	OpenG	(1)	(1)	(1)	(1)	(1)									
6	ScF	0.53 (0.5)	0.58 (0.5)	0.71 (0.5)	0.35 (1)	0.40 (1)	(1)	0.66	0.64						
7	AqF	0.68 (0.5)	0.73 (0.5)	0.72 (0)	0.42 (1)	0.44 (1)	0.56 (1)	(1)	0.55						
8	ReDe	0.29 (1)	0.38 (1)	0.45 (0.5)	0.46 (1)	0.53 (1)	0.75 (1)	0.77 (1)	(1)						
9	IW	(0)	(0)	(0)	(0.5)	(0.5)	(1)	(0.5)	(0.5)	(1)					
10	EI	(1)	(1)	(0.5)	(0.5)	(1)	(0.5)	(0.5)	(0.5)	(0)	(1)				
11	RI	(1)	(1)	(0.5)	(0.5)	(1)	(0.5)	(0.5)	(0.5)	(0.5)	(1)	(1)			
12	Gov	(0.5)	(0.5)	(1)	(0.5)	(1)	(0)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(1)		
13	WA	(1)	(1)	(0.5)	(1)	(1)	(1)	(1)	(1)	(0)	(1)	(1)	(0.5)	(1)	
14	UnIn	(0)	(0)	(0)	(0.5)	(0.5)	(1)	(0.5)	(0.5)	(1)	(0)	(0.5)	(0.5)	(0.5)	(1)

Note: : preserved class,

** : not allow to change,

Value in parenthesis is neighborhood compatibility of classes (1 is High compatible, 0.5 is Moderate compatible, and 0 is Incompatible).

were used to estimate travel rate. The product of length and traffic volume of every link (from junction to junction) of road network were used as impedance in the network analysis. Length or distance of every link was the attribute of road network GIS layer.

The impedance of road network was used for network analysis to obtain the optimum paths of all O-Ds. Optimum paths between all O-Ds in 2016 of 2 case areas were 36,100 and 49,729 paths.

Travel Opportunity

Travel opportunity of people in every pair of O-D (TO_{O-D}) was the product of travel probability of people in a pair of plots and population of the estimated year. The travel probability (TP) of people in a plot (as either O or D) was the division product of people in a plot by the total population of the year estimated. Travel probability of people in a pair of plots was the product of TP of O and D. The people in a plot was estimated from the plot area and the population density of a plot class.

Methodology

Optimization of Urban Growth Planning Using GA-MODA

The planned urban classes of all plots in the study area should serve an optimum goal through GA-MODA which was operated on a set of planning objectives and comply with a set of constraints. The variation of population of plans could be arranged by GA while MODA was employed to optimize multi-objectives required.

Genetic Algorithms (GAs)

The GA, which is capable of handling the unstructured urban issues, was proposed in this field in the 1970s (Hopkins, 1977; Los, 1978). GAs are computationally intensive global search heuristics, or meta-heuristics. The central idea behind GAs is to mimic the Darwinian notion that selective breeding seeks optimum individuals in a given environment (Smith *et al.*, 2007). Malczewski and Rinner

(2015) explain that the basic feature of GA is a multi-directional and global search, while maintaining a population of potential solutions from generation to generation. The population based approach is especially useful for exploring the set of Pareto solutions. The procedure covers steps as optimization problem definition, encoding, initialization, evaluation and fitness assignment, selection, crossover, mutation, and new population. In order to execute a generic algorithm, each potential solution to the optimization problem is encoded to represent possible solutions in form of chromosomes or genome-like objects. Possible solutions in this study mean possible plans for urban plots of the case areas. Chromosomes are made of discrete units, called genes. A number of plots or all genes constitute one chromosome, which in this study is also referred to a land use plan. Each plot which is not assigned as preserve and unchangeable classes is defined as an integer of class ID and varied in different plans of the population. These population plans of each generation are the input of optimization process.

MODA

MODA is the effective fitness function of the GA. The available decision methods of MODA to integrate multi-objectives can be classified into 1) weighted-sum (value function) approaches, 2) the metric-based approaches, and 3) Pareto-based (or dominance-based) approaches (Gen and Cheng, 2000). The most popular method is Pareto-based approach. Instead of providing a single solution or without dominance consideration, the result from Pareto-based approach can provide a set of non-dominated solutions. This allows further flexible consideration to select optimum solution(s) based on a single or a selected group or all objectives.

In this study, the maximin fitness function, one of Pareto approach expressions, is selected to be the decision method for fitness. The function was proposed by Balling (2002). The practical performance of the function is strongly evident in the study of Zhang (2014). The function is employed to measure the goodness of each plan in one generation.

As described by Zhang (2014), the first step of the function is to translate all objectives into the format of “min(Z)”, and then let Ob_{ki} as the value of the k -th objective in the i -th plan. As for the max(Z) format objective, the objective will be transformed to min(Z) format by following Equation.

$$Z = -Z \quad (1)$$

Then consider two plans at a time in one generation, the i -th plan and the j -th plan. The i -th plan will be dominated by the j -th plan if: $Ob_{1i} > Ob_{1j}, Ob_{2i} > Ob_{2j}, \dots, Ob_{ki} > Ob_{kj}$

$$(2)$$

And this equation is equivalent to the following Equation:

$$\min(Ob_{1i} - Ob_{1j}, Ob_{2i} - Ob_{2j}, \dots, Ob_{ki} - Ob_{kj}) > 0 \quad (3)$$

Thus, the i -th plan is a dominated plan if:

$$\max_{i \neq j} (\min(Ob_{1i} - Ob_{1j}, Ob_{2i} - Ob_{2j}, \dots, Ob_{ki} - Ob_{kj})) > 0 \quad (4)$$

And the fitness of the i -th plan is:

$$f_i = \left[1 - \max_{j \neq i} \left(\min \left(\frac{Ob_{1i} - Ob_{1j}}{Ob_{1(max)} - Ob_{1(min)}}, \dots, \frac{Ob_{ki} - Ob_{kj}}{Ob_{k(max)} - Ob_{k(min)}} \right) \right) \right]^p \quad (5)$$

In the above equation, to normalize the difference of each objective comparing between plan to plan, the difference of maximum and minimum values of objectives in plans of a generation are used to scaling. In Equation (5), the scaling factors $Ob_{k(max)}$ and $Ob_{k(min)}$ are the maximum and minimum value of the k -th objective.

Objectives of GA-MODA Setup

For this research, an attempt was to optimize a set of possible objectives for urban planning that met satisfaction of constraints so that the good quality of living in the area could

be maintained and promoted. Six objectives were setup to serve the purpose as follows:

1) Objective 1: To maximize housing capacity

Housing capacity should be sufficient to accommodate the population. The total number of housing people of candidate plan i is the summation of the product of area of residential classes and their housing density in unit of a number of suggested people per rai. The residential classes cover LR, MR, and HRCom.

2) Objective 2: To maximize employment capacity

Employment capacity should be sufficient to provide citizens with jobs. The total number of employment capacity of candidate plan i is the summation of the product of area of classes related to employment and their density in unit of a number of suggested people per rai. The classes about of employment are cover HRCom and RA.

3) Objective 3: To maximize open green area

The environment in urban areas should be comfortable enough to maintain the quality of life in a city. The standard or suggested area for open green space can be varied from country to country and different cities. Open green area of the study can be suggested in forms of square meters per head of population. The open green area of a particular plan is achieved by summing the plot areas of open green space in a plan.

4) Objective 4: To maximize neighborhood compatibility

To minimize conflicts in neighboring land usage is to maximize neighborhood compatibility (Ligmann *et al.*, 2008). Each land use type has its own neighborhood preference (Cao *et al.*, 2012). Therefore, the summed product of compatibility indexes and the areas of a given and neighboring plots including weight is acted as the indicator to reflect the compatibility.

5) Objective 5: To minimize changing cost

Changing cost between two land usages indicates the difficulty of changing from a

certain kind of land usage to other one (Zhang, 2014). The cost implies economic, social, and cultural conflicts that can occur when a plot class is subject to change. Changing cost is higher when greater effort is required or previous investment will be lost. To compute the changing cost of a plan, sum over the changing cost of all changed plots is operated.

6) Objective 6: To minimize travel rate

The optimized plan should have minimization of the traffic congestion where commercial and residential usage were spread throughout the cities rather than concentrated in one or two areas (Balling *et al.*, 2004). Therefore, this study offers minimizing travel rate based on travel probability of people from plot to plot of different classes. The travel rate relies on impedance in terms of distance and traffic volume. Impedance of every path together with travel opportunity were used to estimate travel rate. Thus, the total travel rate of a particular plan was achieved by the summed product of travel opportunity and impedance of a route from original (O) plot to destination (D) plot. The travel opportunity from O plot to D plot will depend on population of those plots.

Constraints of GA-MODA Setup

Objectives in the study consist of optimizing housing and employment capacity, and open green areas. These required constraints setup based on suggested land use rate and existing data and information of the study area. The purpose of constraint setup was to allow the planning class areas and population able to fall into a range of existing and suggested conditions. Therefore, the upper bound and lower bound of constraint elements could be practically flexible or varied according to 2 suggestions of case areas. The lower value of existing area or suggested area/population was set to be lower bound while the higher was set to be upper bound. They were switchable.

The general algorithm to set up constraints was developed (Figure 2). The upper bound and lower bound of constraints in terms of area and population were specifically assigned into relevant classes as listed below.

Constraints 1)-4), 4)-6), and 7) were applied to objectives 1, 2, and 3, respectively.

- 1) $SuggestPop_L \leq Z_{HC} \leq SuggestPop_U$
- 2) $SA_1 \times TotalStudyArea \leq \sum A_{p1} \leq ExtA_1 \times Adj$
- 3) $SA_2 \times TotalStudyArea \leq \sum A_{p2} \leq ExtA_2 \times Adj$
- 4) $SA_3 \times TotalStudyArea \leq \sum A_{p3} \leq ExtA_3 \times Adj$
- 5) $SuggestLB_L \leq Z_{EC} \leq SuggestLB_U$
- 6) $\sum A_{p4} \leq SA_4 \times TotalStudyArea$
- 7) $\sum_{p=1}^n A_{p5} \geq StA_{OG}$

Where, Z_{HC} is housing capacity (total number of housing people of a plan), Z_{EC} is

For better living, constraints were setup to comply with 2 suggestions (mentioned in introduction).
A. Algorithms of constraints setup: Algorithms of all constraints are described below:
1) LR area constraint (Constraint 2): Consider LR class
 If existing/predicted area is lower than the suggested area,
 set existing/predicted area to be "lower bound"
 and suggested area to be "upper bound"
 Else set suggested area to be "lower bound"
 and existing/predicted area to be "upper bound"
Then LR constraint: lower bound $\leq$ Total LR area $\leq$ upper bound
2) MR area constraint (Constraint 3): Consider MR class
 If existing/predicted area is lower than the suggested area,
 set existing/predicted area to be "lower bound"
 and suggested area to be "upper bound"
 Else set suggested area to be "lower bound"
 and existing/predicted area to be "upper bound"
Then MR constraint: lower bound $\leq$ Total MR area $\leq$ upper bound
3) HRCOM area constraint (Constraint 4): Consider HRCOM class
 If existing/predicted area is lower than the suggested area,
 set existing/predicted area to be "lower bound"
 and suggested area to be "upper bound"
 Else set suggested area to be "lower bound"
 and existing/predicted area to be "upper bound"
Then HRCOM constraint: lower bound $\leq$ Total HRCOM area $\leq$ upper bound
4) Housing Capacity (Constraint 1): Consider population of LR, MR, and HRCOM classes
 set lower bound of population =
 (lower bound of LR class area $\times$ suggested population density of LR class) +
 (lower bound of MR class area $\times$ suggested population density of MR class) +
 (lower bound of HRCOM class area $\times$ suggested population density of HRCOM class),
 set upper bound of population =
 (upper bound of LR class area $\times$ suggested population density of LR class) +
 (upper bound of MR class area $\times$ suggested population density of MR class) +
 (upper bound of HRCOM class area $\times$ suggested population density of HRCOM class),
 and set Housing Capacity constraint:
 lower bound of Population $\leq$ Total Population $\leq$ upper bound of Population
5) RA area constraint (Constraint 6): Consider RA class
 If existing/predicted area is lower than the suggested area,
 set existing/predicted area to be "lower bound"
 and suggested area to be "upper bound"
 Else set suggested area to be "lower bound"
 and existing/predicted area to be "upper bound"
Then RA constraint: Total RA area $\leq$ upper bound
6) Labor force (Constraint 5): Consider population of HRCOM (Constraint 4) and RA classes
 (Constraint 6)
 set lower bound of Labor force =
 (lower bound of HRCOM class area $\times$ suggested population density of HRCOM class) +
 (lower bound of RA class area $\times$ suggested population density of RA class),
 set upper bound of Labor force =
 (upper bound of HRCOM class area $\times$ suggested population density of HRCOM class) +
 (upper bound of RA class area $\times$ suggested population density of RA class),
 and set Labor force constraint:
 lower bound of Labor force $\leq$ Total Labor force $\leq$ upper bound of Labor force
7) Open Green area (Constraint 7): Consider OpenG class
 StA_{OG} is recommended total open green area based on area per head, 10 m²/ person.
 StA_{OG} = (Number of Population $\times$ 10 m²) / 1,600 rai
 Then set Open Green area constraint: Total Open Green area $\geq$ StA_{OG}

Figure 2. Algorithm of constraint setup

employment capacity (total number of employment people of a plan), $SuggestPop_L$ is the sum of lower population estimated from either of suggestions of relevant classes, $SuggestPop_U$ is the sum of higher population estimated from either of suggestions of relevant classes, $SuggestLB_L$ is the sum of lower population of labor force estimated from either of suggestions of relevant classes, $SuggestLB_U$ is the sum of higher population of labor force estimated from either of suggestions of relevant classes, A_{pk} is the area of plot p -th with k -th urban class, SA_1 is percentage of suggested area of a LR urban class, SA_2 is percentage of suggested area of a MR urban class, SA_3 is percentage of suggested area of a HRCOM urban class, SA_4 is percentage of suggested area of an RA urban class, $TotalStudyArea$ is total study area considered, $ExtA_k$ is total area of k -th urban class of existing year, Adj is percentage of adjust value of a variable, StA_{OG} is recommended total open green area of the study area based on area per head, p is plot number in a plan from 1, 2, 3, ..., to n , and k is urban class ID from 1, 2, 3, ..., to z .

Simulation of GA-MODA Process For Urban Class Planning

GA process was coded in Matlab® following the designed structural flow of functions and used to simulate urban class planning of case areas. Interpreted land use plots of 2016 (with classes of 2013) in case areas were input for the simulation. Prepared data and information of attributes of objective functions and constraints mentioned above were the input of process. Selected fitness function of GA process in the study was Pareto approach as expressed in Equation (5).

Comparison of Urban Plans From GA-MODA To 2016 Urban Land Use

Optimum urban land use plans resulted from GA-MODA process were expected to be better than existing urban land use of 2016. Objective values of optimum GA-MODA plans of each case area were displayed in range because GA-MODA process provided results as a set of plans. Therefore, there were 3 ways

for comparison, i.e. 1) to check if they complied with constraints, 2) to check if they were at Pareto front, and 3) to compare their sums of normalized objective values (SNOV). All objective values were normalized to be the bigger the better before summation.

Results and Discussion

Setup Objective Functions

The maximized and minimized objective functions were setup and are presented by the following Equations:

$$\text{Objective 1: } \text{Max } Z_{HC} = \sum_{p=1}^n (A_{pk} \times CH_{pk}) \quad (6)$$

$$\text{Objective 2: } \text{Max } Z_{EC} = \sum_{p=1}^n (A_{pk} \times CE_{pk}) \quad (7)$$

$$\text{Objective 3: } \text{Max } Z_{OG} = \sum_{p=1}^n A_{pOG} \quad (8)$$

$$\text{Objective 4: } \text{Max } Z_{com} = \sum_{p=1}^n \sum_{j=1}^{m \in NB_p} Com_{k,l} \times A_p \times A_j \times W_{pj} \quad (9)$$

$$\text{Objective 5: } \text{Min } Z_{change} = \sum_{p=1}^n CC_{h,k} \times NorA_p \quad (10)$$

$$\text{Objective 6: } \text{Min } Z_{trans} = \sum_{d=1}^n \sum_{d=0+1}^n Imp_{0-d} \times T_{0-d} \quad (11)$$

Where, Z_{HC} is housing capacity (total number of housing people of a plan), Z_{EC} is employment capacity (total number of employment people of a plan), Z_{OG} is the total area of open green area, Z_{com} is compatibility of a certain plan, Z_{change} is changing cost of a certain plan, Z_{trans} is total travel rate of a plan, A_{pk} is the area of plot p -th with k -th urban class, A_{pOG} is the area of plot p -th when k is the open green area class, A_p and A_j are the area of p -th plot and neighborhood j -th plot, CH_{pk} is housing density in unit of a number of suggested people per rai for plot p -th with k -th urban class, CE_{pk} is employment density in unit of a number of suggested people per rai for plot p -th with k -th land use class, $Com_{k,l}$ is the compatibility index between the k -th land use class and the l -th land use class, NB_p is the a number of

Table 3. Sets of constraints of each case area

Case area 1	Case area 2
<u>Housing capacity:</u> 1) $381 \leq Z_{HC} \leq 1,520$ 2) $44.04 \text{ (Ex)} \leq \sum A_{i1} \leq 138.68 \text{ (Sug)}$ 3) $0 \text{ (Ex)} \leq \sum A_{i2} \leq 40.80 \text{ (Sug)}$ 4) $16.60 \text{ (Sug)} \leq \sum A_{i3} \leq 46.42 \text{ (Ex*25\%)}$	<u>Housing capacity:</u> 1) $547 \leq Z_{HC} \leq 4,082$ 2) $76.20 \text{ (Ex)} \leq \sum A_{i1} \leq 172.80 \text{ (Sug)}$ 3) $0.81 \text{ (Ex)} \leq \sum A_{i2} \leq 50.84 \text{ (Sug)}$ 4) $20.68 \text{ (Sug)} \leq \sum A_{i3} \leq 203.66 \text{ (Ex*25\%)}$
<u>Employment capacity:</u> 5) $293 \leq Z_{EC} \leq 771$ 6) $\sum A_{i4} \leq 148.53 \text{ (Sug)}$	<u>Employment capacity:</u> 5) $318 \leq Z_{EC} \leq 3,147$ 6) $\sum A_{i4} \leq 185.07 \text{ (Sug)}$
<u>Open green area:</u> 7) $\sum A_{i5} \geq 1.38 \text{ (Std)}$	<u>Open green area:</u> 7) $\sum A_{i5} \geq 8.74 \text{ (Std)}$

neighborhood of p -th plot, W_{pj} is spatial weight between p -th plot and neighborhood j -th plot, $CC_{h,k}$ is the changing cost per unit area from h -th land use class to k -th land use class, $NorA_p$ is the normalized area of p -th plot (0-1), Z_{Trans} is total travel rate of a plan, Imp_{O-D} is the traveling impedance of a route from O plot and D plot, TO_{O-D} is the travel opportunity of O plot and D plot, O is origin plot from 1, 2, 3, ..., to $n-1$, D is destination plot from $O+1$, $O+2$, $O+3$, ..., to n , p is plot number in a plan from 1, 2, 3, ..., to n , k is urban class ID from 1, 2, 3, ..., to z , l is urban class ID of neighborhood plot from 1, 2, 3, ..., to z , f is former urban class ID from 1, 2, 3, ..., to z , and j is a number of neighborhood plots of plot p from 1, 2, 3, ..., to NB_p .

Setup Constraints

Objective constraints of each case area of 2016 were finally setup following the mentioned above algorithm and results are

Table 4. The GA-MODA results of each case area

	Case area 1	Case area 2
Plans complied with constraints	33	710
Plans at Pareto front	26	370
Minimum fitness value	0.63	0.74
Maximum fitness value	0.98	0.99

shown in Table 3. The lower and upper bound of each constraint were related to the suggested population density and class area. For example, in every case area, existing area of HRCom became upper bound of constraint 4). Therefore, 25 percentage increment was required to allow continuous growth in this limit. This practice helps promote the area to have higher opportunity to be one of the transportation and industrial hubs of the region. The upper bounds of constraints 1) and 5) which were mainly dependent on the class area of HRCom were also adjusted to consent with this practice. Regarding of constraint 5), existing area of RA class became the lower bound. Twenty-five percentages reduction of the class was required so that changing from this class to be other classes could happen.

GA-MODA Plans and Objective Values of Case Areas

GA-MODA simulation resulted in a number of urban plans for each case area which complied with a set of constraints and was located at Pareto front. The population size of each running was defined as 3,000 plans. For each case area, this number of plans was input into GA-MODA process to compute objective values and to check how many plans complied with constraints. The plans complied with constraints were proceeded to check whether they were located at Pareto front and ranked by Pareto approach. The ranking process was performed to compare their fitness values. The minimum and maximum of fitness values of each case area are only displayed in the Table 4. The numbers of plans at the front

of Pareto approach for case area 1 and 2 are 26 and 370, respectively.

Table 5. Constraints and objective values of each case area of GA-MODA plans and existing urban land use

Objective	Constraint	Existing	GA
Case area 1			
Housing	381-1,520	221	678-1,137
Employment	293-771	148	488-612
Open green	≥ 1.38	0.70	36.27-130.61
Compatibility	-	666	522-754
Changing cost	-	1.17	4.64-5.51
Travel rate	-	17,937	24,843-52,140
Case area 2			
Housing	547-4,082	1,398	3,214-3,471
Employment	318-3,147	987	2,649-3,011
Open green	≥ 8.74	-	9.29-44.24
Compatibility	-	1,981	1,900-2,062
Changing cost	-	0.03	0.67-0.90
Travel rate	-	11,443	29,788-37,741

Result Comparison of Urban Plans From GA-MODA To 2016 Urban Land Use

GA-MODA plans and 2016 urban land use were compared on:

1) Complying with constraints

According to Table 5, constraint parameters of existing 2016 plans, with respect to objectives of housing, employment capacities and open green areas, could be checked whether they complied with constraints or not. In the objectives of housing capacity and employment capacity, existing of case area 2 complied with constraints while existing of case area 1 was lower than the lower bound. Open green area of both case areas were too small and not complied with constraint. It is essential to note that all objectives of optimum GA-MODA plans complied with constraints and located at Pareto front. Therefore, based on this comparison element, it can be concluded that they can provide better quality of living than existing 2016 plans. Existing plans of case areas show that their populations and labor forces are lower than the lower bound of range of GA-MODA plans. For good quality of living, it indicates that the areas can support more population growth which in turn being able to provide more labor force. Open green area of existing plans are much lower

than of GA-MODA plans. Then, this attribute of each case should be strongly promoted. Compatibility of existing plans fall into the ranges of corresponding objectives of GA-MODA plans. Therefore, based on these objectives they were considered equivalent and can be maintained. Travel rates of case areas were lower than the minimum rates of GA-MODA plans because their urban classes provided much lower population which caused lower travel opportunity and rate.

2) Locating at Pareto front

Two existing plans of case areas were added into the list of optimum GA-MODA plans to perform Pareto approach. The results revealed that they were not at the Pareto front and resulted in not available fitness value. It can be concluded that plans of existing 2016 were completely dominated by optimum GA-MODA plans. Based on this comparison element, GA-MODA plans can provide better quality of living than existing 2016 plans.

3) SNOV comparison

Table 6 shows the results of plan comparison between optimum GA-MODA plans and plans of existing 2016. Even though SNOV cannot point out perfectly better plans but it can imply or confirm MODA plans in each case area are better than of existing plans. results of above 2 comparison elements. From the Table, almost all of SNOVs of GA-MODA plans in each case area are better than of existing plans.

Table 6. Comparison results of SNOV of GA-MODA plans and existing land use

	>	<
	23	3
Case1	(0.0500-0.6290)	((-0.1442)-(-0.00115))
	369	1
Case2	(0.00048-0.7840)	(-0.00465)

Note: 1) > : a number of optimum GA-MODA plans having higher SNOV than of existing land use,
< : a number of optimum GA-MODA plans having lower SNOV than of existing land use.
2) the range of SNOV differences in plan comparison.

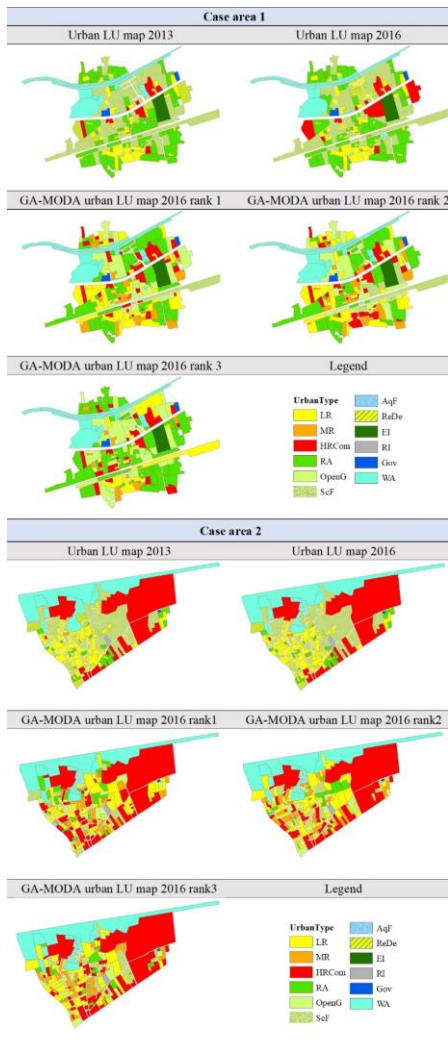


Figure 3. Comparison of existing land use and top 3 GA-MODA urban plans

Comparison Examples of Top 3 GA-MODA Plans To 2016 Urban Land Use

An attempt was made to show a good example of comparison in details. Top 3 on the basis of fitness values of GA-MODA plans were selected to compare with existing plans of case areas. Land use maps of these comparison plans are displayed in Figure 3. Their fitness values, objective values and SNOV are shown in Table 7. By visual comparison of urban land use maps, the better

plan cannot be identified. This is to confirm why fitness value of Pareto front approach is necessary. As known, plans located at Pareto front are non-dominated plans. Their fitness values resulted from considering all objectives in GA-MODA process at once can be effectively identified ranks of non-dominated plans. The higher fitness value indicates the better plan. Similar to the discussion above, objective values of existing 2016 plans were analyzed to show that they were not located at Pareto front and resulted in not available fitness value. This indicates that they were completely dominated by top 3 of GA-MODA plans.

Considering maximized values of objective 1-4 (housing, employment, open green area, and compatibility) of both case areas, ones of GA-MODA plans are apparently the same or higher than of the existing ones. When considering minimized values of objective 5 and 6 (changing cost and travel rate) of both case areas, ones of GA-MODA plans are higher than existing ones. The results can explain that housing capacity, employment capacity, open green area, and compatibility of GA-MODA plans are better while changing cost and travel rate are subordinate. It is obvious that travel rate of GA-MODA plans can be comparatively higher when their populations are higher than suggested population. It can be explained that higher population with more distribution can trigger higher travel activity. The result is strongly confirmed by SNOV. The SNOV of all GA-MODA plans are higher than of existing 2016 urban land use maps.

Conclusions

The main goal of this study is to plan urban land use spatially in a level of individual plot for 2016. The objectives of the study are to develop and simulate a flexible procedure for urban class planning of selected case areas using GA-MODA to comply with constraints, and compare results between existing/interpreted and GA-MODA plans. GA was used on generating population of plans for

Table 7. Top 3 plans based on fitness values, their objective values and SNOV

	Fitness	Objective 1	Objective 2	Objective 3	Objective 4	Objective 5	Objective 6	SNOV
Case1								
Existing	-	687.70	616.17	0.70	666.07	1.17	17,937.00	3.36
GA Rank 1	0.9807	1,071.81	609.82	64.26	620.84	4.98	43,436.72	3.51
GA Rank 2	0.9775	1,074.70	604.29	64.09	614.10	5.00	40,537.66	3.55
GA Rank 3	0.9559	835.59	609.31	88.07	725.16	5.06	31,827.33	3.83
Case2								
Existing	-	2,723.26	2,482.54	NA	1,980.50	0.0298	11,443.00	3.30
GA Rank 1	0.9992	3,460.12	2,914.46	23.31	1,975.57	0.82	34,882.50	3.61
GA Rank 2	0.9991	3,394.84	2,794.42	27.02	1,999.03	0.73	34,291.55	3.76
GA Rank 3	0.9990	3,433.30	2,851.70	22.02	1,996.32	0.70	33,850.24	3.72

Note: NA: not available,

- : fitness value is not available because of not being at Pareto front

fitness test. MODA was applied to fitness evaluation under given objectives and constraints. Objectives cover sufficient housing, employment, open green area, high compatibility, and minimized changing cost and travel rate. For better living, constraints were setup to flexibly comply with 2 suggestions: 1) suggested areas and population densities to urban classes and 2) suggested population densities for actual urban class areas.

To be evident that GA-MODA plans were better than existing plans, the comparison based on 3 aspects 1) if they complied with constraints, 2) if they were at Pareto front, and 3) if SNOV of GA-MODA plans were better than existing plans. The results show that there are no existing plans completely comply with constraints while all GA-MODA plans do. None of existing plans was located at the Pareto front while all GA-MODA plans were. More than 90 percentage of GA-MODA plans having higher SNOV than of existing plans. It could be confirmed that GA-MODA is the capable process to generate a number of optimal plans having better comparison elements than of 2016 plans. The flexible GA-MODA procedure designed in this study can balance all objectives to meet the optimized values which are better than of existing plans. The procedure was designed to

be able to apply to other areas with their own constraints and characteristics.

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