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Ridership Optimization Model of Transit-Oriented Development in Jakarta

Abstract. Transit-Oriented Development (TOD) is an urban planning concept focusing on sustainability. One of TOD's functions is to encourage the use of public transportation and increase the number of transit ridership. Several studies have focused on planning TOD to increase the number of transit users, but it only focuses on planning at the station area level, which relates to the gross floor area (GFA) of land-use development as the decision variable. This research is intended to fill the gap of previous research by offering an optimization model for land-use allocation based on linear programming and system dynamics at the parcel level of TOD on built-up land based on Mass Rapid Transit (MRT) to maximize MRT transit passengers. The objective of this research is to obtain the optimal GFA for each property development to achieve the maximum level of passenger travel. This study found that the optimal land composition to produce maximum ridership was residential by 27%, commercial by 23%, offices by 11%, government by 12%, hotel by 5%, and other land development by 22%. The potential increase in ridership with this land composition can increase up to 6% from the daily average of the existing MRT Jakarta ridership today.

Keywords: Land-use; Optimization model; Ridership; TOD

1. Introduction

Urbanization in Indonesia continues to increase yearly, data from 2010 – 2020 states that the level of urbanization in Indonesia has risen to 56.64% (Statista, 2022). Urbanization occurs for many reasons, such as land use changes, job hunt , access to education and health services, hopes to improve living standards, and massive urban growth (Hidayati, 2021; Widiawaty, 2019). However, rapid and irregular urban growth often presents challenges such as traffic congestion, air and water pollution, loss of green land, and increased social inequality (Murakami et al., 2015). Therefore, a development concept that focuses on sustainability is needed to overcome the negative impacts of urbanization and ensure the quality of the cities for the community.

Transit-Oriented Development (TOD) is a sustainability-focused concept (Saroji et al., 2020). Peter explained that TOD is a mixed-use community centered around transit nodes like trains, Bus Rapid Transit, or rapid transit systems to reduce reliance on private vehicles (Carlton, 2007). TOD has two business interests: transit operators aim to increase passenger numbers, and property businesses aim to raise land values around stations (Transport Research Board, 2004). With the development of the TOD concept and changes in land use with the main function of increasing the use of public transportation, the ridership from the main transit transportation in the region is expected to reach the optimal number (Huang et al., 2021; Wey et al., 2016).

The Government and PT. MRT Jakarta have recognized the importance of sustainable urban development and are implementing it by developing five MRT stations with TOD concepts: Lebak Bulus, Fatmawati, Blok M (including Blok M and Sisingamangaraja Stations), Istora Senayan (including Istora Mandiri and Senayan Stations), and Dukuh Atas (MRT Jakarta, 2019a). The TOD development aims to reduce private vehicle use by providing public transportation and promoting walking and cycling. Additionally, the MRT was built to alleviate congestion that the TransJakarta lane could not solve due to bus lane and road overlaps (Ardi et al., 2024). It also aims to improve access to jobs and economic resources and increase land value in nearby areas.

Several studies have focused on TOD planning that can increase the number of transit users (Khosravi et al., 2024), but it's only focused on station-area-level planning, not parcel-level, which relates to the Gross Floor Area (GFA) of land-use development as its decision variable. This study intends to fill the gap of previous research by offering a land-use allocation optimization model based on linear programming and dynamic systems at the parcel level of TOD on MRT-based built-up land to maximize MRT transit passengers. The focus of this research is to obtain the optimal GFA for each property development as an alternative approach to transit operations and property development planning to achieve maximum levels of passenger travel. The study focused on the utilization of space within TOD areas to generate optimal ridership from their development, which is crucial to ensure that TOD development is not in vain and can maximize its own functions. By analyzing and creating a TOD Optimization model, the results can be used as a guideline for future improvements and benchmarks for other TOD masterplans across Indonesia. The potential future improvements include providing clear guidance on how residential rental prices are affected by proximity to transit stations and other geospatial factors, and how transportation planning and land use can be better integrated to create more affordable housing and fairer distribution (Yang et al., 2024).

2. Literature Review

2.1. Travel Demand Modeling

In this study, modeling was carried out using trip generation and modal split to obtain the number of ridership from the five TOD MRT Jakarta area plans. Trip generation aims to predict the number of trips raised and drawn by each TOD. This stage of the model development process only focuses on the number of trips that begin or end in each area, but not creating relationships between zones (Fithra, 2018). The next stage is a modal split that aims to predict travel: the choice of travel mode makers (Vanoutrive & Huyse, 2023). The value of modal split in this study was obtained from the average value of modal split obtained by literature studies, and TOD benchmarks in several countries.

2.2. TOD Benchmark

This study adopts the study's results (Berawi et al., 2020), which identify three successful TOD areas based on Cervero's 'variable D': density, diversity, design, accessibility, and distance to transit. The first is Union Square in Kowloon, Hong Kong, featuring a mixed-use development with an integrated transit station. The second is Namba Park in Osaka, adjacent to Sekai station and including shopping arcades and other facilities. The third is D-Cube City in Seoul, a complex with direct access to Shindorim Station. Berawi's research details the variables used to analyze these successful TODs as follows:

Table 1 TOD Variables

Dependent Variables	Independent Variables
Density	- Floor Area Ratio (FAR) - Gross Floor Area (GFA)
Diversity	- Residential - Office - Hotel - Retail / Commercial - Other

Design **Destination** **Accessibility** **Distance to Transit**	- -	Building Configuration Development Configuration

These TOD variables will be reviewed for each TOD location along the Jakarta MRT Phase 1 corridor and will be compared with the variables from the three benchmark TOD locations.

3. Methodology

In calculating ridership in this study, a basic approach of travel demand modeling was utilized, which only encompasses trip generation and modal split. This research is divided into two stages of approach with qualitative and quantitative methods to obtain two research objectives: (1) developing a basic model for TOD passenger mode and (2) figuring out how TOD mixed land use will optimally increase transit passengers. To achieve the first goal, the basic function and proportion of mixed land use must be determined by analyzing TOD functions, comparing TOD models through literature studies, and collecting TOD Benchmark data from various countries that successfully increase the number of transit ridership. To achieve the second goal, the Optimization model is obtained with a linear programming approach (LP) and dynamic systems, which are then analyzed comparatively both in terms of differences between existing ridership, their relationship with existing capacity, and their relation to operator business and the value of surrounding land.

The study location is in five Jakarta MRT TOD development plans located along the south-north corridor of MRT Jakarta Phase 1: TOD Lebak Bulus, TOD Fatmawati, TOD Blok M-Sisingamangaraja, TOD Istora-Senayan, and TOD Dukuh Atas as can be seen on Figure 1. The detailed design data for the development of the TOD project comes from the DKI Jakarta Governor's Regulation on City Design Guidelines (PRK) for Transit-Oriented Development Areas from the five TOD areas. Research data is secondary data obtained from PT Integrasi Transit Jakarta, which will then be added with data from TOD Benchmarks.

This location was chosen because the five MRT TODs represent the largest TOD plans currently in Indonesia, with all TOD developments in other areas benchmarked against these five TOD zones. Therefore, a detailed study on land optimization in these five TODs is necessary to generate optimal ridership, serving as a foundation for TOD development in other areas.

Figure 1 Map of MRT Jakarta Network and Location of Study Area (MRT Jakarta, 2019b)(adjusted: Study Area)

3.1. *Linear Programming*

The calculation of daily ridership using the approach of area per capita requirement is an effective method for areas with incomplete development details (Hendrigan & Newman, 2017). To create a linear program model, three main components are needed: the goal function, the constraint function, and the decision variable (Hillier & Lieberman, 2021). To formulate a linear program model, transit ridership is modeled as a goal function where magnitude must be maximized. A combination of each land use's GFA is used as a decision variable to maximize the objective function. The decision variable's limitation is the land availability in each TOD area. Then the linear program model in this study can be defined as follows:

$$Max\ Z = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \alpha_6 X_6 \quad (1)$$

Where Z is the amount of ridership resulting from a combination of six decision variables: Residential (X_1), Commercial(X_2), Office (X_3), Government(X_4), Hotels (X_5), and Others (X_6). While $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$, and α_6 are the coefficient of the generation rate of transit travel of each land-use. The constraint function is defined as each land use (equation 2 & equation 3). The constraint function is defined as each land use's maximum and minimum GFA percentage.

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 \leq GFA\ max \quad (2)$$

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 \geq GFA\ min \quad (3)$$

3.2. *Dynamic System Model*

The main principle of system dynamics is to provide a detailed understanding of how each element interacts, provide optimal system performance results, and predict future system performance. Several things affect the relationship of the system: Causal Relationship, Stock & Flow, Delay, and Nonlinear. Dynamic system modeling in this study is only affected by Causal Relationships and Stock & Flow.

A causal loop of each variable and stock flow diagram is used to determine the optimization model precisely using the dynamic system. From the figure below, we know the causal relationship between each variable (Figure 2(a)). After defining the causal loop, the relationships between all the variables can be drawn on the stock-flow diagram to create the dynamic optimization model of ridership for each land use (Figure 2(b)). The ridership value is obtained from the sum of the land area of each land use multiplied by the trip rate and modal split of each land use. The travel behavior of individuals in the Jabodetabek area involves making trips between one to three times per day (JICA, 2019). Therefore, the trip rate is utilized to represent this value. The relationship of each land-use is mutually reducing because there are boundaries in the form of existing land TOD areas, so the GFA percentage of each use will change dynamically depending on the increase and decrease in GFA of each land-use combination. The stock-flow diagram isz made as the relationship depicted in the causal loop, where in making a dynamic system model in this study, the help of the PowerSim application was used to obtain a ridership optimization model in the five TOD MRT Jakarta study areas.

One example of using this method is conducted by Ewing, who utilized system dynamics to determine that in TOD areas, pedestrian rates are at 45.8%, and railway users are at 16%. These figures are significantly higher compared to Transit-Adjacent Development (TAD) concepts, which only reach 3.6% for pedestrians and 4.1% for railway users at Orenco Station (Ewing et al., 2019). This method is also employed for Airport Characterization in Hub-and-Spoke Networks in Yuliawati's study (Yuliawati et al., 2015).

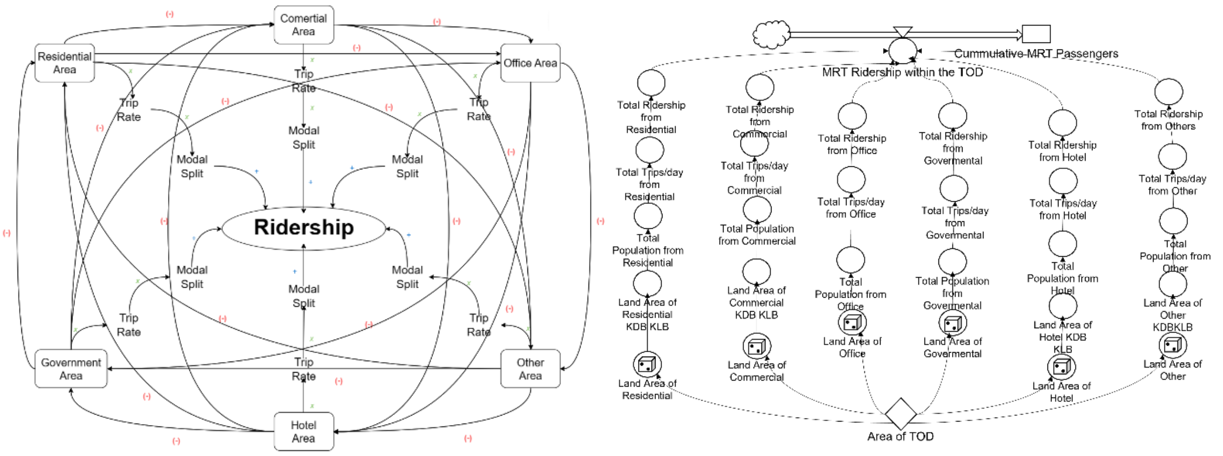

Figure 2 (a)Causal Loop(left) and (b) Stock Flow in This Study(right)

3.3. Benchmark TOD Model

Benchmark results from successful TOD in three countries became the main guidelines for this study. Each of the 'variable d' of TOD Union Square, Namba Parks, and D'Cube City will be analyzed. Regarding design variables and destination & transit accessibility, Union Square has the most efficient integration design where residential, office, and other buildings sit atop the commercial podium housing the Kowloon station; In addition, a multifunctional area located at a distance of about 200 m from the transit station encourages residents to walk because easy and convenient access is available.

By variable Diversity, it is known that five land uses must exist to meet the diversity level of a TOD area, namely: Residential; Commercial; Urban; Hotel; and Other land development. 'Other' means land use for Green Space, Blue Space, Road access, etc. As for variable density, calculated by percentage values Floor Area Ratio (FAR) obtained from the division between the total floor area / GFA and land area. The results obtained FAR values from all three regions Benchmarks in the range of 6.79 – 8.07 with an average FAR of 7.43. The composition of the type of land development, GFA, total land area, and FAR of each TOD Benchmark is summarized in Table 2.

Table 2 Land Composition on TOD Benchmark

Landuse		**TOD Area**			**Range**
		Union Square	**Namba Parks**	**D'Cube City**	
Residential	m^2	608,026	60,000	110,300	24–56%
	%	56%	24%	26%	
Comertial	m^2	82,750	86,000	107,800	8–34%
	%	8%	34%	25%	
Office	m^2	231,778	60,000	24,480	6–24%
	%	21%	24%	6%	
Hotel	m^2	167,472	0	18,360	4–15%
	%	15%	0%	4%	
Other	m^2	0	44,700	171,000	18–39%
	%	0%	18%	39%	
Total GFA	m^2	1,090,026	250,700	431,940	
Total Land Area	m^2	135,000	33,700	636,00	
FAR	m^2	8.07	7.44	6.79	

3.4. Existing MRT Jakarta TOD Development: Case study

The five TOD plans in Jakarta are in the areas that have been built and have their respective functions and zoning, as reported in the DKI Jakarta Governor's Regulation regarding RDTR in 2022. The zoning division is contained in the Jakarta MRT TOD Area City

Design Guide (PRK), where the composition of existing land in the Jakarta MRT TOD area plan can be seen in Table 3, while the plan for additional land development is in Table 4. The composition of existing land in each TOD area is diverse. Land development is classified into 6: Residential, Commercial, Office, Government, and Others consisting of green space, blue space, road access, terminals, educational facilities, worship facilities, and health facilities. Meanwhile, the plan to add land according to PRK, is not diverse enough, which only includes adding land for affordable housing (residential) and affordable business space (commercial) and additional developments such as adding green space, open plazas, and accessibility support facilities. Even in TOD Istora-Senayan, there is no additional function of residential and commercial land because, based on the results of multi-criteria analysis, the study of affordable housing development in TOD Istora-Senayan does not allow for the development of affordable flats. The main factors are due to the area's land value, which is already very high, the availability of land, and the absence of assets owned by the DKI Jakarta Provincial Government in the area.

Table 3 Composition of Existing Land in MRT Jakarta Area Plan (m^2)

TOD Area	Residential	Commercial	Office	Government	Other	TOTAL GFA
Lebak Bulus	744,600	302,493.8	558,450	162,881.25	332,674	2,101,099
Fatmawati	911,390.4	250,185.6	446,760	53,611.2	82,468.8	1,744,416
Blok M-Sisinga	929,611.2	319,553.9	352,754.25	1,016,762.25	271,993	2,890,675
Istora-Senayan	276,432.8	1,013,587	650,430	92,144.25	161,746	2,194,340
Dukuh Atas	1,079,670	1,169,643	1,270,200	134,958.75	300,680	3,955,152

Table 4 Additional Land Development Based on PRK (m^2)

TOD Area	Residential	Commercial	Office	Government	Other	TOTAL GFA
Lebak Bulus	31,050	124,804.5	0	0	30,519.7	186,374.2
Fatmawati	33,000	99,170.5	0	0	32,816.9	164,987.4
Blok M-Sisinga	18,000	232,224	0	0	12,529	262,753
Istora-Senayan	0	0	0	0	48,400	48,400
Dukuh Atas	396,000	631,085	0	0	1,5903.4	1,042,988

Because the planned area is not vacant land, all types of land development need to be considered to determine the amount of ridership generated from each TOD area. A summary of the design development of the five TOD MRT Jakarta in terms of land-use allocation and the proportion of floor area is presented in Table 5. From PRK, five TOD areas were obtained, including Lebak Bulus, Fatmawati, Blok M-Sisingamangaraja, Istora-Senayan, and Dukuh Atas; it can be seen that the orientation of TOD area development is only focused on residential and commercial properties that take a large portion of TOD land-use, while the development of office areas is not carried out because there are already around 21% of the total GFA from the existing area. It can also be seen that there is no type of hotel development in the entire TOD area.

Table 5 Land Composition and Number of Ridership in MRT Jakarta TOD Plan

Landuse		TOD Area					Average
		Lebak Bulus	Fatmawati	Blok M-Sisinga	Istora-Senayan	Dukuh Atas	
Residential	m^2	626,730	898,820.88	947,611.2	276,432.75	1,367,703	33%
	%	34.04%	56.45%	33.46%	13.35%	29.13%	
Comertial	m^2	366,799.45	274,300.42	503,844.72	912,228.07	1,683,763.25	27%
	%	19.92%	17.23%	17.79%	44.06%	35.86%	
Office	m^2	446,760	268,056	299,841.11	598,395.6	1,143,180	21%
	%	24.27%	16.84%	10.59%	28.90%	24.35%	
Government	m^2	154,737.18	35,740.8	818,493.61	92,144.25	134,958.75	9%
	%	8.41%	2.24%	28.90%	4.45%	2.87%	
Hotel	m^2	-	-	-	-	-	0%
	%	-	-	-	-	-	
Other	m^2	245,918.95	115,285.7	262,498.23	191,455.9	365,428.14	9%
	%	13.36%	7.24%	9.27%	9.25%	7.78%	
Total GFA	m^2	1,840,945.58	1,592,203.8	2,832,288.88	2,070,656.57	4,695,033.14	
Total Land Area	m^2	750,000	576,000	1137000	990000	1450000	
FAR	m^2	2.455	2.764	2.491	2.092	3.238	2.608
Ridership	Trip/day	177,616	142,598	298,926	227,698	483,652	266,098

Ridership calculations are obtained using the value of the required space per person and the value of the modal split. The value of the minimum required space from each landuse is refer to some standard such as SNI 03-1733-2004, and other (Badan Standarisasi Nasional, 2004; Mohammed Ali Berawi, Saroji, et al., 2020; Hung et al., 2009; Maryanti et al., 2016). The modal split value is refere to some jurnal for each landuse (Aoki et al., 2017; Mohammed Ali Berawi et al., 2021; Clifton et al., 2015; Nelson & Sanchez, 2018; Vincent et al., 2012; Wang et al., 2019; Wen & Yu, 2019; Yin & Liu, 2018). Both required space per person and the modal split was then elaborated on with each other.

The smallest value of the minimum required space per person is used because TOD is a high-density development, so the allocation of space per person must be minimal but within the standards set in the building planning criteria. However, for the 'other' type of development, because it consists of several land development types, an average of the required space per person for each type of land development is used. While the value of the modal split is obtained from the average value from various literature studies, which is TOD that successfully improves ridership train on every type of development.

Thus, to calculate the magnitude of the ridership value, a parameter of the generation rate of transit travel is needed (see Eq. (1)), where the value is obtained by multiplying the modal split value of rail transport and the area of space required per person in the building plan (Table 6).

Table 6 Parameter for Determining The Objective Function of Ridership

Landuse	Required Space per Person (m^2/person)	Person/ m^2	Modal Split	Estimation of Train Trip Person/ m^2
Residential	9.29	0.11	68.5%	0.07
Commercial	4.62	0.22	54%	0.12
Office	4.64	0.22	67.2%	0.14
Government	4.64	0.22	72%	0.16
Hotel	5	0.20	49%	0.10
Other	5.31	0.19	47.2%	0.09

Berawi, in his research, did not calculate 'other' land functions because it was assumed that the type of development was in the form of green space and did not produce a large travel generation. However, in this study, other types of land development are a combination of various types of development that can provide travel generation, the value of area needs per person, and modal split from this development function is the average of several values owned by the land functions of green space, blue space, road access, terminals, educational facilities, worship facilities, and health facilities. With this land composition, the average daily ridership of the five TOD areas is 266,908 trips/day.

4. Result and Discussion

4.1. Ridership TOD Model: Linear Programming

The linear programming optimization model is based on the diversity parameter of the TOD benchmark as a function of constraints, where the GFA composition range of each type of development is used, and the parameters in Table 8 are used as trip generation rate to obtain the destination function (see Eq. (1)). Because the study area is an area that is already built up, there is an additional boundary function; the total GFA of all types of development must be less than the total GFA of the TOD area. Another limiting function is that the GFA of each type of development must be in the range according to the composition of the land in the TOD benchmark (Table 2). In addition to fulfilling the diversity parameter, there must be six development types in a TOD area. So based on the explanation above, the ridership optimization model with the linear programming method can be defined as follows:

$$Max\ Z = 0{,}07X_1 + 0{,}12X_2 + 0{,}14X_3 + 0{,}16X_4 + 0{,}10X_5 + 0{,}09X_6 \tag{4}$$
$$24\% \leq X_1 \geq 56\%\ of\ GFA \tag{5}$$
$$8\% \leq X_2 \geq 34\%\ of\ GFA \tag{6}$$
$$6\% \leq X_3 \geq 24\%\ of\ GFA \tag{7}$$
$$6\% \leq X_4 \geq 24\%\ of\ GFA \tag{8}$$
$$4\% \leq X_5 \geq 15\%\ of\ GFA \tag{9}$$
$$18\% \leq X_6 \geq 39\%\ of\ GFA \tag{10}$$
$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 \leq GFA \tag{11}$$
$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 \geq 0 \tag{12}$$

The above model is used to optimize the composition of land development types to maximize the MRT's daily ridership in the Jakarta MRT's five TOD areas. Where eq. (4) is the basic function for computing land optimization, and equation 5 – equation 12 represent the constraint functions of the basic function. So based on the linear programming optimization model, the composition of land that produces maximum ridership is obtained, namely: residential 28%; commercial 18%; office 12%; government 14%; hotels 4% and others 24%, where the average daily ridership generated from each TOD area is 275,686 trips/day or an increase of about 5% from ridership with land composition by the PRK plan. The summary of the percentage of land composition and ridership of each TOD area can be seen in Table 7.

Table 7 Land Composition and Number of Ridership in The Linear Programming Optimization Model

Landuse		TOD Area					Average
		Lebak Bulus	Fatmawati	Blok M-Sisinga	Istora-Senayan	Dukuh Atas	
Residential	m^2	749,466.26	397,808.65	679,749.33	496,957.5	1,126,807.95	28%
	%	41%	25%	24%	24%	24%	

Comertial	m²	178,676.80	338,120.88	601,876.01	421,399.53	740,197.46	18%
	%	10%	21%	21%	20%	16%	
Office	m²	150,995.28	241,021.45	275,503.77	337,956.04	568,591.51	12%
	%	8%	15%	10%	16%	12%	
Government	m²	189,110.52	241,021.45	425,384.49	337,956.04	568,591.51	14%
	%	10%	15%	15%	16%	12%	
Hotel	m²	73,637.82	78,814.81	119,466.63	103,669.16	197,770.59	4%
	%	4%	5%	4%	5%	4%	
Other	m²	499,058.89	295,416.54	730,308.64	372,718.18	1,493,074.05	24%
	%	27%	19%	26%	18%	32%	
Ridership LP	Trip/day	178,766	174,952	302,676	230,319	491,716	275,686
Ridership Increasement	Trip/day	1,150	32,354	3,750	2,621	8,064	9,588
	%	1%	23%	1%	1%	2%	5%

4.2. Ridership TOD Model: Dynamic System Modeling

In the dynamic system optimization model, the α quantity is not used to determine the trip generation rate of each type of land development (Equation. 1). To replace it, the average trip per day generated from each type of development is used. The value is derived from a survey of travel behavior conducted both through paper-based and mobile-based methods involving residents of the Jabodetabek region(JICA, 2019; Wismadi et al., 2013).

The calculation of ridership with a dynamic system model is depicted as a stock-flow diagram in the PowerSim application based on causal loops such as Figure 3. The GFA composition range of each type of land development from the TOD benchmark is also used in this method as a limitation. The dynamic system determines various alternative land compositions that can occur with existing borders. The ultimate goal is to get the most optimal composition of land development types to get the maximum ridership size. So based on the dynamic system optimization model, the most optimal land composition is obtained to produce maximum ridership, namely: residential 27%; commercial 28%; office 10%; government 10%; hotels 5% and others 19%, where the average daily ridership generated from each TOD area is 287,557 trips/day or an increase of about 11% from ridership with land composition by the PRK plan. The summary of the percentage of land composition and ridership of each TOD area can be seen in Table 8.

Table 8 Land Composition and Number of Ridership in Dynamic System Optimization Model

Landuse		**TOD Area**					**Average**
		Lebak Bulus	**Fatmawati**	**Blok M-Sisinga**	**Istora-Senayan**	**Dukuh Atas**	
Residential	m²	482,211.57	422,280.66	826,449.32	586,449.32	1,233,868.80	27%
	%	26%	27%	29%	28%	26%	
Comertial	m²	567,556.52	437,854.10	920,351.93	474,069.68	1,207,496.58	28%
	%	31%	27%	32%	23%	26%	
Office	m²	175,429.36	170,144.43	226,998.50	226,998.50	537,416.72	10%
	%	10%	11%	8%	11%	11%	
Government	m²	170,858.71	180,845.59	219,863.02	219,863.02	537,141.51	10%
	%	9%	11%	8%	11%	11%	
Hotel	m²	114,285.41	87,042.14	136,696.71	106,696.71	238,375.81	5%
	%	6%	5%	5%	5%	5%	
Other	m²	330,604.04	294,036.88	501,929.74	456,579.74	940,733.72	19%
	%	18%	18%	18%	22%	20%	

Ridership DS	Trip/day	195,542	182,376	309,386	245,512	504,970	287,557
Ridership Increasement	Trip/day	17,926	39,778	10,460	17,814	21,318	21,459
	%	10%	28%	3%	8%	4%	11%

A Comparison of the land composition of the future TOD with the Optimization model can be seen in Figure 3, where the most optimal land composition model in the Jakarta MRT TOD to generate maximum ridership is with a residential land composition of 27%, commercial 23%, offices 11%, government 12%, hotels 5% and other types of land development by 22%. With this land composition the daily MRT ridership can increase up to 5% in Lebak Bulus TOD, 25% in Fatmawati TOD, 2% in Blok M-Sisingamangaraja TOD, 4% in Istora-Senayan TOD, and 3% in Dukuh Atas TOD.

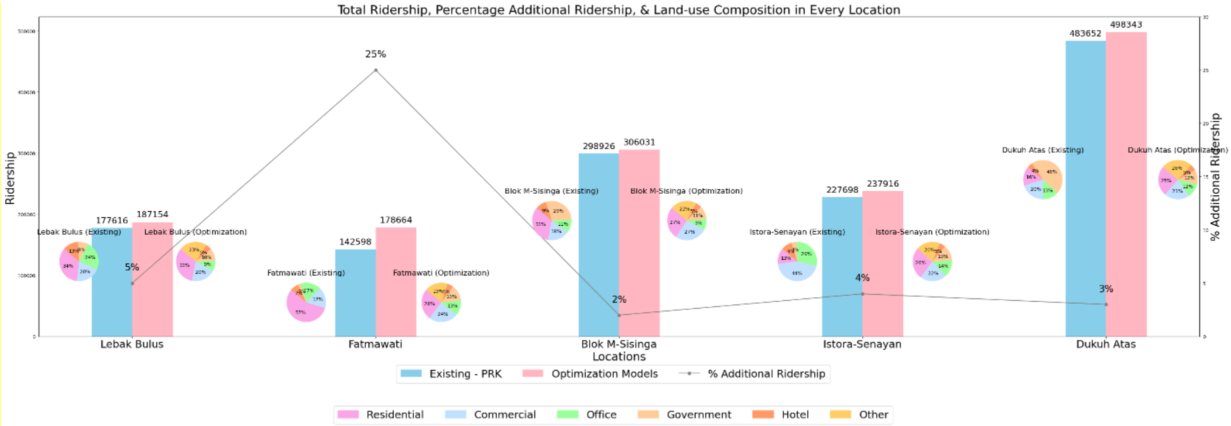

Figure 3 Total Ridership, Percentage Additional Ridership, & Land-Use Composition in Every Location

4.3. *Comparison with MRT Jakarta Capacity*

Another question that needs to be discussed after the creation of this model is whether the Jakarta MRT transit operator can accommodate all potential ridership daily resulting from the development of the five TOD areas along its corridor. It is known that currently, PT MRT Jakarta (Perseroda) applies an operating schedule at 05.00-24.00 WIB every day, valid Monday-Friday with an interval of train departures every 5 minutes during on 7.00-9.00 WIB and 17.00-19.00 WIB, otherwise every 10 minutes. While on weekends, MRT Jakarta operates from 05.00-24.00 WIB with an interval of departure time every 10 minutes. The capacity of a series of Jakarta MRT trains is 1950 people. It is recorded that the number of MRT Jakarta ridership from January 1st, 2023, to April 25th, 2023 reached around 9.4 million people with an average number ridership daily of 81,000 people/day.

The average daily ridership will increase to 281,622 people/day. This means the daily ridership will increase by three times from the current condition. TOD characteristics have a significant positive impact on MRT station. Stations located in areas with stronger TOD characteristics tend to have higher ridership compared to those in areas with weaker TOD characteristics (Khosravi et al., 2024). With a capacity of 1950 people in a series that operates for 6 hours during peak hours and 13 hours during normal hours in a day, it is known that the capacity of the MRT in a day is 292,500 people. It should be noted that 281,622 people/day is the average daily ridership. However, when viewed in detail in Table 9 and Table 12, the daily ridership capacity of some TOD areas exceeds the current capacity of the MRT Jakarta.

The daily ridership from the Dukuh Atas TOD area is 504,970 people/day (Table 8), so to be able to accommodate all passengers, the required frequency from the MRT is every 4 minutes for 19 hours of operational time. The potential for improvement ridership is likely to increase even higher, considering that the average FAR of these five TOD regions is only 2,608 (Table 5). While the TOD parameter as a high-density area must have a FAR value of 5 – 11 (Gubernur Provinsi DKI Jakarta, 2022; Iskandar et al., 2021). Therefore, PT. MRT Jakarta needs to accommodate the anticipated increase in ridership by significantly expanding the GFA of developments in all five regions. PT. MRT Jakarta should also focus on improving the frequency and coverage of transit services to provide equitable mobility options for residents in these areas (Zhao et al., 2024).

4.4. TOD Ownership System and Its Impact on Operator Business & Land Value

According to Cervero & Guerra, one of the main functions of TOD is to increase train ridership and operator revenue (Guerra & Cervero, 2010). In many cases, TOD development has been shown to increase rail usage and generate additional revenue for transit operators (Berawi et al., 2019). Cervero & Landis's research shows that TOD in U.S. metropolitan areas, such as Portland and Denver, has significantly increased rail ridership and carrier revenues (Cervero & Landis, 1995). Transportation operators, such as East Japan Railway Company (JR East) and West Japan Railway Company (JR West), play a crucial role in providing transportation infrastructure that supports TOD. They frequently collaborate with developers to ensure that stations and transportation routes are well-integrated into urban development plans (Utsunomiya et al., 2023).

In Indonesia, TOD ownership is not always owned by transit operators. For example, in the Istora-Senayan TOD area, no land is owned by the DKI Jakarta government. In contrast, TOD development in Indonesia often involves private parties, property developers, or other business entities with land ownership around transit stations. The lack of synergy between traffic operators and TOD owners in Indonesia can be a burden in optimizing TOD's potential to increase ridership. In Taiwan, transportation operators such as Taiwan High-Speed Rail Corporation and local rail companies invest in the development and enhancement of transportation infrastructure. They collaborate with the government to ensure effective integration between stations and surrounding land use. For successful TOD, synergy among government, transportation operators, private developers, and the community is crucial. The government handles regulation and planning, transportation operators provide infrastructure, private developers build properties, and the community offers feedback and benefits from the development (Yen et al., 2023).

The lack of synergy between stakeholders can hinder increased ridership due to the lack of alignment in the development of the area around the station with transit operators' needs and operational strategies. Effective implementation of TOD can provide significant benefits in increasing the value of land around transit stations. By turning the land around the station into an integrated hub activities with the public transport system, the value of the land will increase substantially.

5. Conclusions

This study aims to create a model of land-use allocation optimization based on linear programming and dynamic systems at the parcel level of TOD on MRT-based built-up land to maximize MRT transit passengers. The main focus of this research is to obtain the optimal GFA for each property development as an alternative approach to transit operations and property development planning to achieve maximum levels of passenger travel. Based on the results of the study, it is known that the optimal land composition to produce maximum ridership is residential by 27%, commercial by 23%, offices by 11%, government by 12%, hotels by 5%, and other types of land development by 22%. The potential result of increasing ridership with the composition of the land can increase up to

6% from the current average daily ridership of MRT Jakarta. One of the challenges of implementing this TOD model is that land ownership is held by more than one party because this TOD is built on land that has already been built up, so the government needs an appropriate land consolidation strategy to produce an ideal land composition.

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