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Supporting needy student in transportation : a population based school bus routing in spatial environment

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Abstract—**The city government of Surabaya has offered free school tuition to help needy students. However, free tuition is not enough for some because school costs, like transportation, are not covered with the tuition fee. This project designs free school bus models to help needy students with transportation costs. The model proposed in this research is focusing to find the best routes which cover the area with the most number of potential passengers, the needy student. The needy density in a sub-sub-district area is the primary data. This needy population data will accompany street map, school map, and bus depot in the VRP process. The proposed routes from VRP process then graded in its time consumed, covered area, sharing area, and road balance. Next, the chosen route used in an accessibility analyst in order to find its affect in existing transportation system. The result indicates that the process proposed in this project can be used to find the best route and can support the government in making a decision in the limitation they have.**

Needy student, Vehicle routing process, spatial techniques, coverage analyst, load analyst, school bus.

I. INTRODUCTION

Surabaya, the second-largest city in Indonesia after Jakarta, lies at the eastern part of the island of Java. Surabaya has a total of 492,495 school-aged citizens, with 270,076 at the elementary school age, 114,733 at the lower secondary school age, and 107,686 at the upper secondary school age. There are 1,622 elementary schools, of which 564 are public, and 1,058 are private; 342 secondary schools, of which 42 are public, and 300 are private; and 257 high schools, of which 33 are public, and 224 are private. With the number of elementary schools, about 5 times more than the secondary schools and 7 times more than the high schools, students must travel greater distances as they advance to higher levels of education.

The government of Surabaya has calculated the participation rate of each education level. The participation rate is a comparison between the numbers of students in a certain education level with all citizens at the respective age level. In early 2008, in Surabaya, the elementary school participation rate was 92.92%, the secondary school participation rate was 79.85%, and in the high school participation rate was 83.53%. These figures indicate that there are more than 19,000 citizens of elementary school age, more than 23,000 of secondary school age, and more than 17,000 of high school age who are not participating in school. The primary reason these citizens are unschooled is that they cannot pay schooling costs because they live in needy families. The Surabaya city government has taken action by waiving tuition costs in many public schools. In early 2008, there were 544 elementary schools and 58 secondary schools that did not collect admission costs and monthly costs from their students. The schools that still collect costs from their students, can waive costs for needy students, if the student showing documentation of need from sub district government. The government has not yet made some high schools free because the government is still focusing on the national education target "nine years of compulsory study." This target dictates that all Indonesian people should study for a minimum of nine years at the elementary and secondary levels. However, even with free admission and no monthly costs, there are still numerous children who cannot go to school because they have no extra money for transportation or for buying uniforms, shoes, books, and other school supplies. The purpose of the project addressed in this paper is to provide help in transportation costs.

This research focused on the north area of Surabaya, which has the largest number of needy students, due to the internal limitations. All the spatial and tabular data used in this project represent this area. This project also limited the scope to needy secondary school students. However, the model developed here is not dependent on these limitations. The model can be easily used for surveys of other areas in Surabaya, for the needy in elementary or high school, and for any other places in other country.

II. LITERATURE REVIEW

Bus routing has gained the attention of many researchers in various fields. Some researchers are focusing on the making new algorithms, while others are advancing existing algorithms and applying existing algorithms to the real-world problems [1][2][3]. Robert Bowerman et al. [4] contributed to the advancement of algorithms by introducing a multi-objective approach to modeling the urban school bus routing problem. They developed a heuristic algorithm and tested it with data from a sample school board location in Wellington County, Ontario, Canada. They defined several optimization criteria to evaluate the desirability of a set of school bus routes.

Several studies have reviewed school bus routing methodologies [5][6][7][8][9][10]. Based on the number of schools, bus routing can be divided into the many-to-one and many-to-several methodologies [11]. An example of many-to-one can be viewed in the work of M. Fatih Demiral et al. [12] and Nayati Mohammed [13]. Both used one school location as a depot and a student home location for the customer location to generate bus routes. These authors worked with study areas in Isparta, Turkey, and Hyderabad, India, respectively. Other authors are Li and Fu [14] and Bektas et al. [9]. Li and Fu implemented a heuristic algorithm for the existing data of a kindergarten in Hongkong, whereas Bektas et al. used integer programming for an elementary school in central Ankara, Turkey. These authors saved 29% and 26%, respectively, for their newly generated routes compared to the then current implementations. Based on the location or environment of the data, bus routing can be divided into urban [15][16] and rural areas [17][9]. The many-to-one method of Bektas et al. and Li and Fu can be a good example of applications for urban areas. For rural areas, Armin Fu¨genschuh [18] took five counties in Germany as the student locations. Another work focusing on rural areas is using rural school data in Savigny and Forel, Switzerland [19]. These two rural areas find buses routes for multiple schools.

Other researchers have focused on analyzing existing routes or transportation systems. Melissa Reese analyzed the rapid bus transport system in Curitia, Brazil [20]. She used a 3D presentation to display her analysis. The coverage of facilities is another aspect that can be analyzed. The work of David A Schilling et al [21] is an excellent review of this research. Most analyses use a buffer to represent and formulate the coverage area. The buffer uses distance as its primary parameter. Numerous researches, especially in accessibility of transport systems, has calculated this distance. Most researchers take 400 meters as the recommended maximum distance from a place to transport lines [22][23][24][25]. This project concerns an urban area and multiple schools, and does not focus on the advancing route algorithm. Considering its illustrious effectiveness in the presentation of routing problems, this project used GIS and its applications as the primary tools. The recent Djikstra algorithm adopted in ArcGIS 9.3 is using for vehicle routing problem (VRP) analysis. This study focuses on the process of providing appropriate data and settings used for the VRP process, and it provides analysis after the generated routes. In this study, the data processing and analysis uses one essential parameter: distance. Distance, as used here, refers to the maximum acceptable distance for a needy student to traverse to arrive at the bus line from their home and or school. Because the study area is a tropical zone, and the objects are not adults but children in their early teens, this project decreased the distance from value of 400 m, as used in most research, to 300 m.

III. Study Area

Several collected data use in this research. There is needy citizen database, region map, school location, bus depot location, street map, and the existing transport system map.

A. *Needy citizen data*

The Surabaya city government has collected needy citizen data. In 2007, 550,783 people of the 119,219 families registered lived below the poverty line. This needy people survey recorded name, birthplace, birthday, address, sex, and occupation.

B. *Region map*

The Surabaya city government only has a map with sub-district detail. Consequently, a survey for mapping the sub-sub-district boundary of the project's study area had to be conducted. The total number of sub-sub-districts in this study area is 274. The needy citizen data then filtered in order to select people from 13 to 15 years old. The process continue with convert to a DBF file, so it can be use to assimilate with map data and to copy to the sub-sub-district map. A total of 8,579 needy students were spread throughout this 274 sub-sub-district..

C. *School map and bus depot*

There are 57 schools in this study area consist of 8 public schools and 49 private schools. Public schools are schools owned by the government. These schools serve both purposes because they commonly have appropriate buildings and surrounding areas. Most importantly, the government has a right to manage these areas. So they can act not only as places for delivering and picking up students but also as bus depots. Completing the actual two bus depot reside in the center and west area.

D. *Street map*

There are Highway Street, Primary Street, Secondary Street, and Tertiary Street in this study area. This research uses Primary and Secondary Street. Highway Street is eliminated because it cannot use for picking up passengers. Some of Tertiary Street that can be passed by bus is also included. However, this existing street map cannot apply directly for this research. Street map used in the ArcGIS Network Analyst requires a special format. It needs to conduct some digitizing work for fulfill this format. This map also has to be equipped with "drivetime" field. It determined how much time is needed for a bus for traverse each street.

Street map and previous maps called basic map. Figure 1 shows this map. Street map is shown in red line, school map in green dot, public school in blue rectangle, and bus depot in blue dot. The needy area symbolized in the gradation color of sub-sub-district area. Area with darker color mean has more number of needy students than the lighter ones.

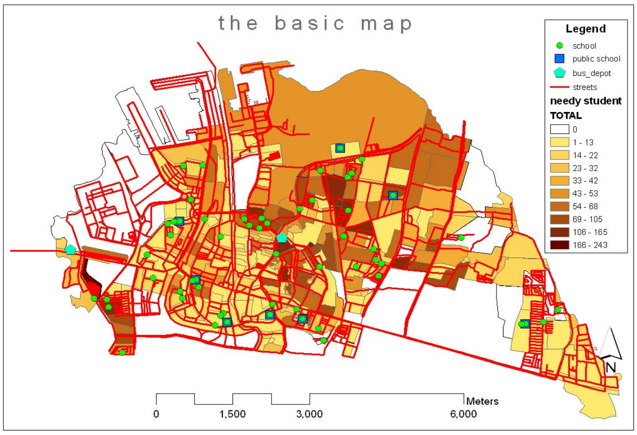

Figure 1. The basic map.

E. *Existing transportation system map*

To understand the impact of the newly proposed school bus system, this research will analyze the current condition transportation system first. In Surabaya, there are several transportation systems that can be used, including taxi, becak, lyn, and bus. The becak is a traditional vehicle that does not have an engine but is powered by paddling, like a bicycle. The becak is used for near-distance traveling. Taxis and becaks have no established routes, depending rather on the passenger's need, and their cost is relatively high for needy people. The lyn is a modified station wagon car. The lyn removes the usual seats in the second and third rows and replaces them with long seats patched at the left and right sides. Buses in Surabaya are like typical buses in other cities, having a capacity of about 50 passengers. The lyn's capacity is about 10 passengers. There are numerous routes covering Surabaya, but in the north region, there are only 13 lyns and 2 buses. There is no documentation of how many fleets there are and when they pass through the region. A survey in a certain time window was conducted. This survey also looked at how many students of secondary school age use this transportation at that time. Figure 2 shows the existing transport system.

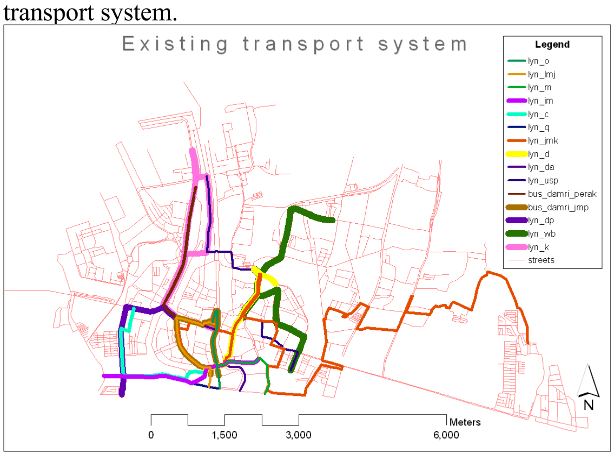

Figure 2. The existing transport system map.

IV. METHODOLOGY

Process in this research divides into 3 stages; the initial stage, the routing stage, and the analyst stage. Figure 3 shows this 3 stages equipped with its steps and data.

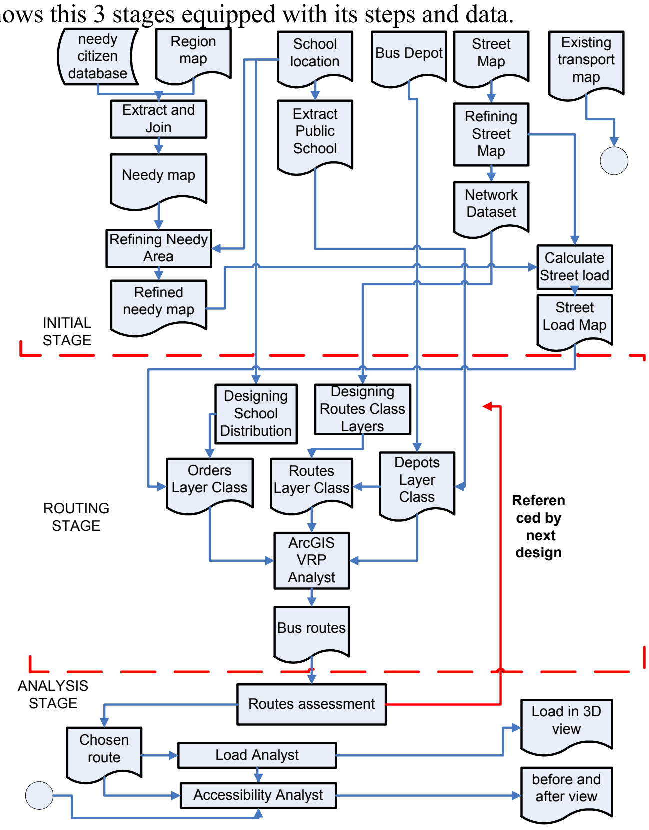

Figure 3. Methodology.

The important step in those 3 stages are:

A. *Refining needy area*

In the previous section, it determined that the number of school is 57 while the number of needy student is 8,579. Each school can be set to provide 155 seats in order to cover all needy students, which can be called needy capacity. However, not all students will need to ride the bus. Government can eliminate the number of needy passenger with a rule that forces the needy to choose a school near their home. With this rule, the needy capacity of each school will be reduced by the number of needy students surrounding it. Some schools may be eliminated from the bus route if the needy capacity is filled because they lie in poor neighborhoods. This step will refine the raw needy area to become the real needy area that must be covered with bus routes.

The process for this refinement is as follows. First, make a neighborhood area for each school, then calculate how many needy are in these areas. Second is comparing the neighborhood's needy number with the needy capacity of each school. This step will determine how many needy fulfill the capacities in each school and how many needy are still left in the surrounding areas. If any school has its capacity filled by the surrounding needy, this school will be eliminated, because a school bus will not need to deliver needy student to it. After this process, the needy students are reduced to 5,265, and the schools are reduced to 48.

B. Calculating street load

In the vehicle routing, some of the process needs to accumulate a load of passengers while traveling. The load value is calculated from the computation of the number of the needy surrounding each road which traveled. For this calculation, it needs to prepare a field, which can represent the load value. The process is a little bit similar with the process of calculating needy surrounding schools. This time, the school points changed with the road parts.

C. Vehicle Routing Problem analyst

The main resource for building the network dataset is a street map. As long as it has standard field names, the process will automatically detect and use data to generate the network dataset. After the dataset has been built, the process continues with determining the settings of the VRP class. At a minimum, the VRP class must set 3 sub-classes, which are Orders, Depots, and Routes. This step also has an optional setting sub-class called Breaks. First is defining the Orders. Orders are places that must be visited by the vehicle. These can be locations for delivering something, picking up something, or just visiting. After the refining process, the total number of schools was 48. All 48 schools were imported as Orders, with the service time set to 2 minutes and the time window set from 6:00 am to 7:00 am. Two different school distributions made for several route designs. These two different school distributions can be seen in Figure 4. Another layer to be imported to Orders class is the street load. It imported with time window 5:30 am to 7:00 am and service time set to 0 because it just a place for a visiting point.

Next is Depots. In school bus routing, the bus starts from the bus depot, travels to and visits schools, and ends up at another depot. The bus may come back to the starting depot, or it may stay in the destination depot until the end of school and then reverse the same route. As mentioned earlier, there are two bus terminals that can be used as depots. Also, there are other available places that can act like depots, the public schools. The depot has a service time and time window parameter. The service time is set to 2 minutes, and the service time is set to 5:30:00 am to 7:00:00 am. This setting means the depot can start loading the bus at 5:30:00 AM and have enough time to travel and pick up passengers before visiting the first school at 6:00:00 AM.

Sometimes a bus on a route needs directions to pass over a certain street and sometimes not to pass. Barriers are used to omit streets from traveling route. Some streets in the map lie outside the study area (northern Surabaya), while some streets lie in east and center areas. This project does not focus on streets outside the study area, and including these streets will make the route unproductive and will waste time. Therefore, barriers are needed here.

Now the Routes class can be defined. The less fewer number of routes mean more school choices for the students. For example, say all schools can be visited in one route, the needy can choose to go to any school in that route. If there are two routes, the schools will be divided into two paths, and the student can only choose about half of all the schools. It was found that the minimum number is 4. These 4 routes are named with west route, east route, north route, and south route. The capacity of each route is limited by the student capacity in its direction. After the route has been generated, the process continues with analyzing the covered area. Because there are several Depots available, the generated route and analysis of the covered area are held at several times with some combination of depots used.

D. Route Assesment

Next step after routes have been proposed is analyzing the routes. The aspects to be analyzed as follows:

- Traveling time. The less traveling time consumed the better the route. After the VRP process is done, the traveling time of each route can be easily read.
- The covered needy. The more the needy can cover the better the route. To find how many needy can be covered, a covered area analysis must be performed. The Analyst uses a buffer with a reference distance of 300 m, as mentioned earlier. This buffer clips the sub-sub-district areas to make sub-sub-district areas that are near the route. After continuing with recalculating the total number based on the needy density field, the total needy that live near the route can be found.
- Number of needy in the sharing area. The sharing area is an area that lies near two routes or more. The greater the number of needy in a sharing area means the better the route. Each route destination must be calculated independently to find this area. After finding the covered area of each destination, this step continues with combining two different routes and calculating their intersections. Intersection areas will be produced that are west-east, west-north, west-south, east-north, east-south, and north-south. All intersection areas will then be joined with Union process.
- Balance of the school capacity and the covered area of the route. The process to find this balance need each route to be separated from the others and their loads calculated individually. This number is then compared with the total school capacity in this route.

E. Load Analyst

Above criteria are calculated and compared for all output of the VRP engine. The best route will be chosen and continue with load analyst. In general, there are 3 crucial processes in load analysis. Those are: dividing each route into small parts, calculating the dynamical of the number of passenger in it, and showing this changing in good presentation. In the first step, the street will be divided into parts. Every part will have a sequential id number that increment from starting depot to end depot. Next, every part needs to be calculated how many needy surround them. A series of buffer, identify, select, and dissolve process need to conduct. The number of surrounded needy then copied in the Load field of the parts. The process is similar with the process in calculating street load. While that process calculating covered needy in each street, this time it calculates the needy covered for each 300 meter part. The second step is calculating this part's load with summing up the covered needy number when traveling along from the depot to the destination, and subtracted with the school capacity if meets a school. If there is some passenger left when arrived at the destination depot, a reverse calculation is needed.

F. *Accessibility Analyst*

There are two data to be processed in the accessibility analyst, the existing transport system routes and existing transport system routes that have been added by four direction school bus in the previous section. Each route is buffered and equipped with the total number of sheets as the value. Then, all routes are converted to a raster so that the value can be processed in a mathematical operator. This process is using the spatial plus operator. Some areas will have a high level of accessibility when there are many seats summed up from many different routes in there. Areas with fewer routes and seats will have a low level of accessibility. The accessibility analyst also calculates how many needy that uncovered by the transportation system.

V. THE RESULT

The initial stage is done in one time while the routing stage is done in several times. The analyst stage is done in several times in the routes assessment, and one time in load analyst and accessibility analyst. Each route direction then detailed to discover its characteristic. Then it will be more explained after the load analyst. The load analyst will produce the changes of passenger time to time while travel from center depot to each direction. This load will be shown in 3D in order to make it easy to understand. Figure 4 shows the chosen route and Figure 5 shows each passenger load in 3D visualization.

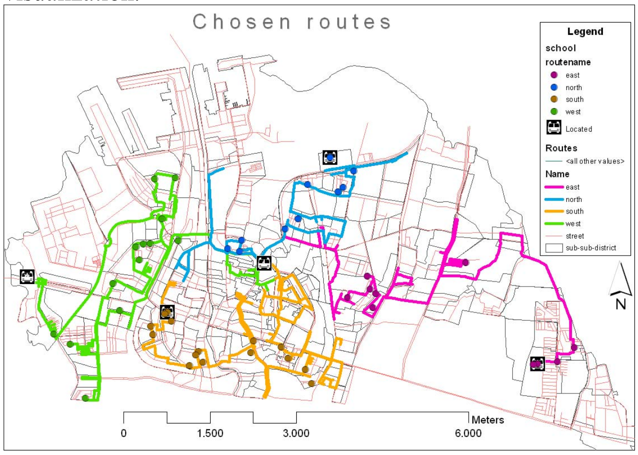

Figure 4. The chosen routes.

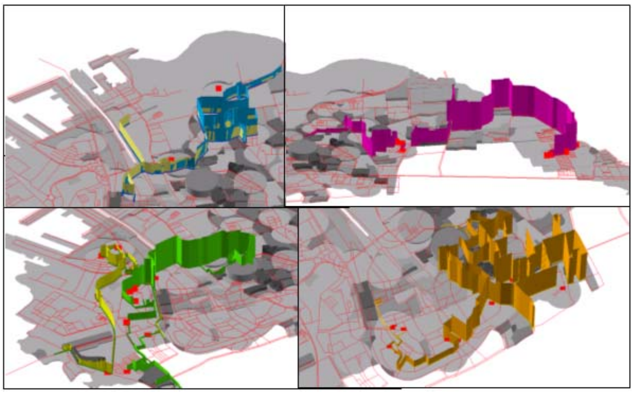

Figure 5. The 3D view of passengers load

It is discovered that north route has a two-way bus route for covering all its needy and delivering to all their schools. The main direction has a maximum number of passengers of 475, while the opposite flow has a maximum passenger number of 248. The south route needs the most number of bus fleets for the main direction because the maximum is 1,115, while the opposite flow needs few because it has a maximum of 53. The west route's main direction has a maximum number of 632, while the opposite flow is 269. Finally, the east route has a maximum number 761. The school's location makes it not need a reserve direction.

The load analyst result can predict the passengers load in each route. With this prediction, the government can make a decision of how many buses that needs to be provided. Say, the bus can carry about 70 needy (50 sitting and 20 standing). The west route will need 9 fleets to the main direction and 4 fleets for the inverse. The east route needs just for its direction, with the number of the fleet is 11 buses. The north route needs more inverse than the others. The main direction needs 7 fleets and for the inverse needs 4 fleets. The south route has to provide the most fleets in the main direction. It needs 16 fleets.

To get new accessibility level after bus schools has been provided, above school bus fleets above bring into the existing transportation system. The existing accessibility level and the new one used to subtract the needy area to make an uncovered needy map. There is 4523 needy student who uncovered by the existing transportation system. After added with the bus schools, the uncovered needy decreased to 1341 needy. Figure 6 shows the accessibility level of existing transportation system and the new transportation system after the bus school was added.

VI. CONCLUSION

With methodology proposed in this research, the pattern and correlation between needy and schools can be discovered, and the optimal solution can be chosen. This research has proposed the most minimum traveling time bus school routes, cover the most number of needy students, and divide the area in favorable distribution. With the load analyze method; this project can predict how many buses need to provide to covers all orders completely. Even, In this case study, the numbers of buses to be provided may be a great number for the government, the government still can use this calculation number for a reference to distribute their limited number of buses wisely.

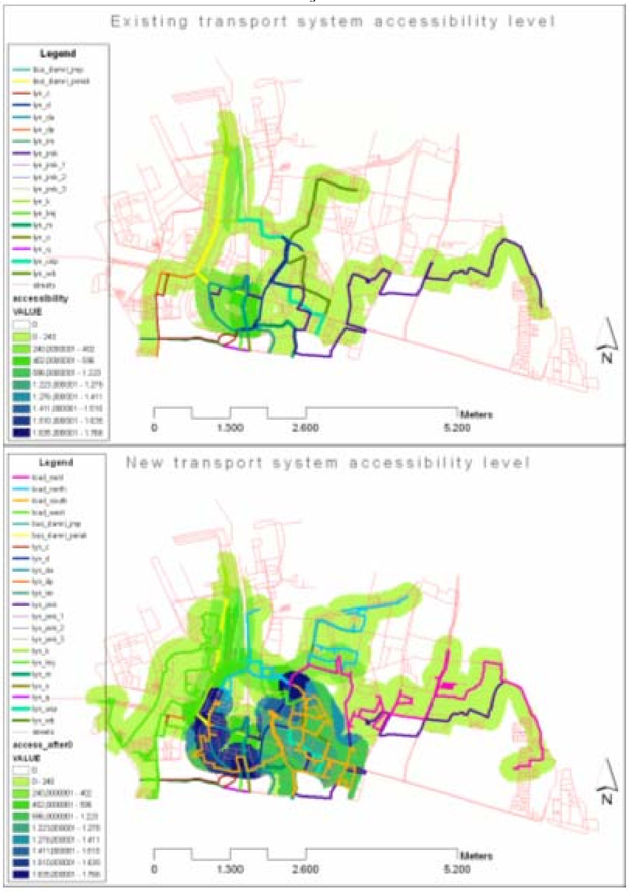

Figure 6. Accessibility map before and after added with bus schools.

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