A Multi-Criteria Approach in Designing Bicycle Tracks

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1. Introduction

The National University of Singapore (NUS) has ten faculties offering undergraduate and graduate programmes. The buildings of the different faculties have clustered in different parts of the campus depending on whether they are science, engineering, arts, business or medicine-related. Also, the seven residence halls are scattered all around the campus. Recent changes in the curriculum of the programmes offered by the faculties have emphasized a broad-based education, cross-disciplinary interaction and increased flexibility for students to determine their own individual study program. This inevitably requires the movement of students within the campus and campus transport is presently being provided by three separate internal shuttle bus (ISB) services that ply the campus. However, the limitations of the current road geometry, an undulating terrain, and a mature campus, have severely constrained any further increase in the frequency of service of the ISB or expansion of their routes. It has been suggested that an alternative non-motorized mode of transport be considered to alleviate current peak hour traffic jams and to cope with future increases in cross-campus transportation demand. The introduction of cycling routes is considered as one alternative to reduce the peak hour ISB jams.

Figure 1. NUS Campus Map

1.1 Cycling as an alternative

The consideration of introducing cycling routes to alleviate the student flow problem within NUS is motivated firstly by the encouraging results from studies of successful cycle route

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implementations within various European Union countries. Secondly, students and employees of the campus will stand to gain from the various social and environmental benefits associated with commuting via cycling. Thirdly, the introduction of cycling routes would encourage students to change their mode of transport, and would split student traffic that is now confined to that of using the ISB alone; thereby effectively alleviating current peak hour traffic jams. This also aid in coping with the future increases in cross-campus transportation demand within NUS.

In many developed countries, particularly the European Community, cycling policy has in recent years gained wider appreciation as a cheap and affordable means of transport, particularly suitable for short trips (1). Cycling routes of varied magnitude have been successfully implemented in the European cities of Bilbao, Ferrara, Dublin and Geneva, amongst others (2). It is also seen that cycling can contribute much to the enjoyment of travel and to the mental as well as physical health of riders (3).

The list of presumed or proven advantages to be gained from cycling has never been established exhaustively. However, from various literature sources, the following benefits are derived through the implementation of cycling routes within NUS campus:

- Economic benefits including reduced traffic congestions in terms of occurrences and durations, reduced parking problems and savings in the cost of providing and maintaining car parks. All these imply more efficient use of land.
- Social benefits include reduced community severance and increased community interaction. Interaction of students and staff alike from different faculties may be enhanced depending on the pattern of the route networks.
- Ecological benefits include reduced noise and air pollution, enhanced preservation of greeneries and improvement to the attractiveness of the campus. In other words, the quality of campus living will be enhanced, providing the community with a conducive and pleasant environment to work in.

1.2 Demerits of cycling as an alternative

Having justified the selection of bicycle route as the alternative mode of transport to reduce the traffic problem, discussion on the demerits cannot be neglected. Most of the time, cycling is often associated with only regions which are sufficiently flat. The reason is obvious: cycling demands a muscular effort and must therefore be practiced in flat terrains. Given the undulating contours of NUS, this is indeed a major drawback of cycling as a form of commuting from point to point. Secondly, it is certainly true that there are too many accidents which involve cyclists. Safety is a real problem for cyclists, as it is for pedestrians, which explains the recent legislation to discourage cycling on pedestrian pavements. Riding among vehicles which are often traveling substantially faster, cyclists are also at the mercy of car and heavy vehicle drivers.
Effort has been taken to incorporate these two shortcomings of cycling into the analysis, so as to achieve an acceptable, if not pleasant level of comfort, to commute using bicycles within the campus. As will be elaborated later in the paper, the multi-criteria approach stems from these two shortcomings. More specifically, attempt is made to seek the feasible routes by minimizing the number of safety violations and the degree of inclination of the routes by representing them as the objective function.

The last point for contemplation is the influence of weather. Singapore, being a tropical country with high humidity and unbearable heat during some time of the day, may not be the best location to encourage commuting via cycling. In reality, research by the European Commission (1999) reveals that the climatic features which have a really dissuasive influence on cyclists are pouring rain and snow. However, the short distances of trips within the campus considered, appropriate clothing and a suitable infrastructure greatly reduce the negative impact of atmospheric conditions. Though these observations were derived from the European countries, with suitable ancillary facilities, the detriments of the local weather can be negated effectively.

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Discussions on the merits and demerits of using the bicycle as a mode of transport warrants further investigation on the possibility of designing bicycle routes for intra-campus commuting.

2. Study Objectives and Scope

With the target set to design the feasible cycling routes that can cater to the needs of the population in NUS, the objective has been defined in stages that would finally project the best feasible bicycle network of the campus:

1. To determine the origin and destination points based on the student flow.
2. To derive the constraints and multiple criteria evaluation function from the literature review and field studies.
3. To formulate the constraints and evaluation function into the appropriate mathematical equivalent capable of analysis in a GIS environment.
4. Perform analysis to obtain potentially feasible cycling routes using GIS.
5. To verify the feasibility of the cycling routes found through field investigation.

In addition, the scope of the analysis is set to be bounded within the campus and the 4 major roads of Ayer Rajah Expressway in the north, Clementi Road in the west, South Buona Vista Road in the east and Pasir Panjang Road in the south. Furthermore, it is assumed that the hostellers will be the main users of these cycling routes for commuting since they spend most amount of the time in campus. This extent of analysis, as defined by the scope, provides a reasonable framework of study, without compromising on the validity of the results produced as the most pertinent issues and factors are addressed. Extension of the scope is possible after critically analyzing the results of this pilot investigation.

3. Analysis Methodology

This section discusses the modeling process involved in the study. The analysis procedure goes in line with the listed objectives where the preliminary groundwork of defining the origins-destinations, constraints and evaluation function pertinent to the project analysis is presented first. This is followed by a discussion on the procedures of preparing the initial data sources of the relevant raster layers that are capable of performing GIS analysis with respect to the constraints and evaluation function defined. The details of the major GIS analysis, some of the difficulties that were faced in performing these analysis and the methods in overcoming these difficulties will also be discussed. Finally, in view of the uncertainty of the GIS data and the changing nature of the campus landscape, the feasibility study that was conducted to verify the results from the GIS analysis through actual field studies is also discussed. In cases where the potential routes violate the feasibility constraints in reality, minor amendments on the routes derived to overcome these violations are proposed.

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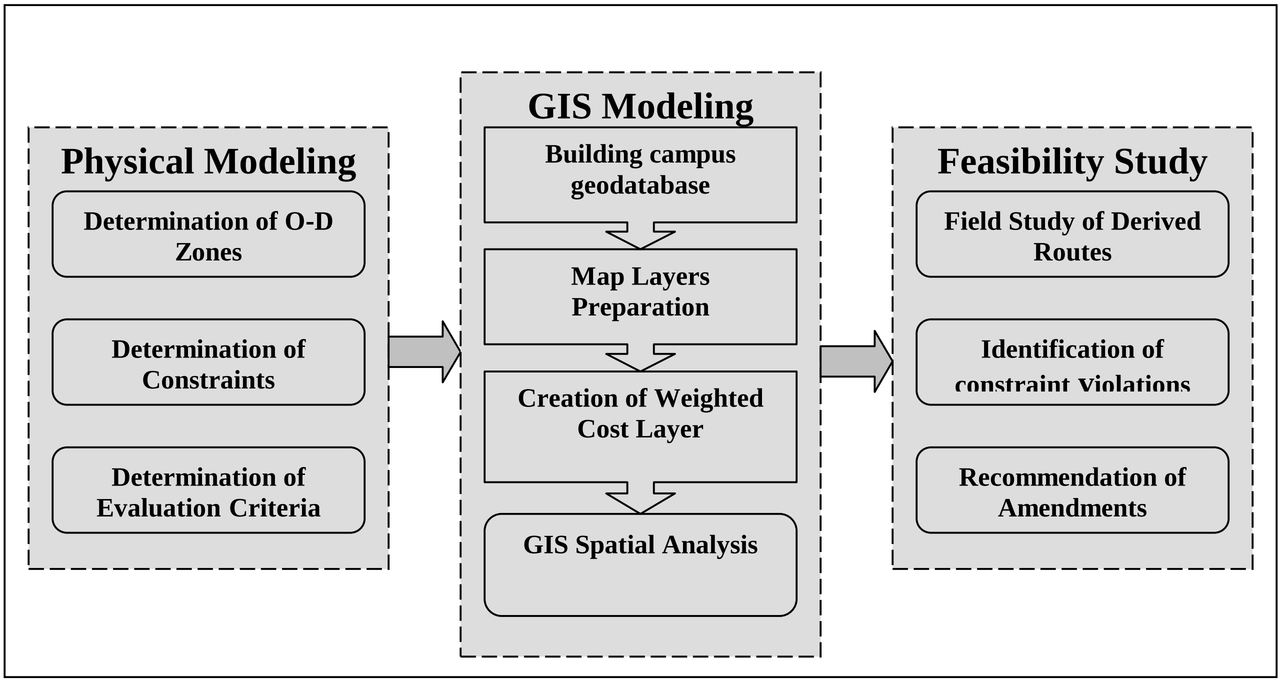

Figure 2. Overview of Analysis Methodology

3.1 Physical Modeling

In the physical modeling process, the origin and destination zones are first identified based on the widely used *desire line diagram.* This is ensued by defining the pertinent constraints to be considered when planning and designing a cycling route. Based on a similar research done at the University of Queensland, Australia (4), three primary constraints pertinent to the project are identified: slope of the route, distance from the roads and distance from the major infrastructures. Finally, the criteria for the analysis have been narrowed down to safety, accessibility and the existing land use.

3.1.1 Determination of Origin-Destination (O-D) Zones

Desire lines are the straight lines connecting trip origin and destinations of travel desire where the thickness of the lines indicates the relative amounts of travel desire (5). Travel patterns vary with different peak hours of the day. Different desire lines drawn for different time periods can be overlaid to get all the potential O-D zones. In case of NUS, the morning peak hour demand is generally between the residential halls to all the faculty buildings. Setting this as the baseline and considering the demand because of cross faculty studies, the strategic zones include all the residential blocks and the faculty buildings. Figure 3 shows the desire lines and the strategic O-D zones based on NUS students flow data. The thickness of the line visually shows the student flow between the zones.

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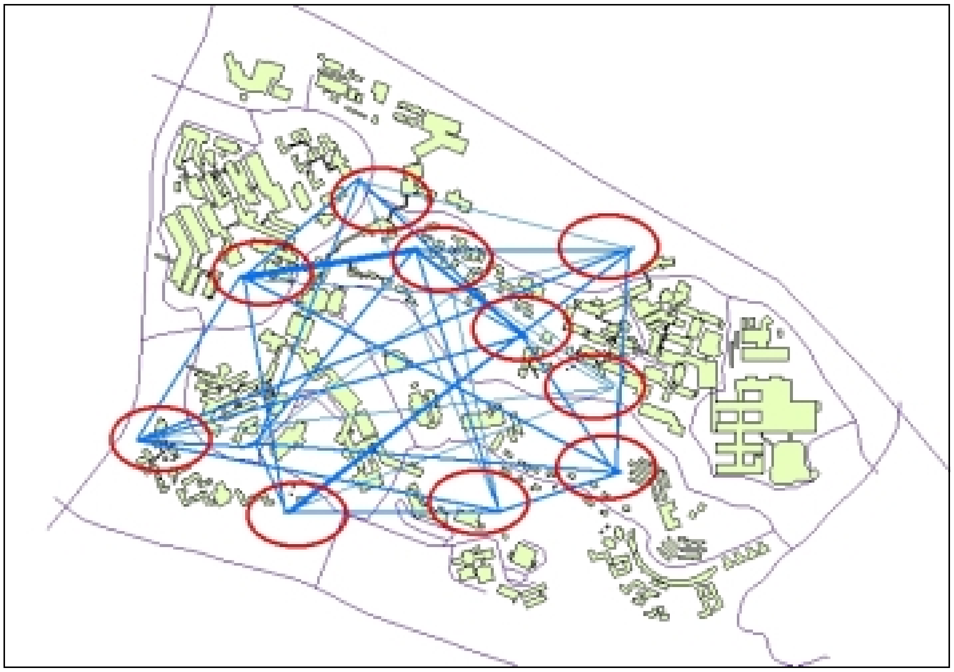

Figure 3. Desire line diagram showing potential O-D zones

3.1.2 Determination of Constraints

Three groups of criteria relating to the planning for cyclists can be identified which includes cyclist's criteria, criteria for other mode users and other criteria. Cyclist's criteria points to the aspects of safety, continuity, directness, convenience, acceptable grades, road surface, air quality, noise and parking facility. Criteria for other mode users should also be met while planning for bicycle tracks. The safety of non-cyclists must not be impaired, and inconvenience though unavoidable, must be minimized. Other criteria pertain to aspects like space, existing land use and cost involved in the project.

Considering all these criteria together and based on the nature of data available, this study specific design constraints are formulated with an underlying emphasis on accessibility, safety and existing land use. The accessibility factor includes the distance of trip for which the tracks are designed and the gradient of the area under study. The safety factor is taken into account based on the cyclists' accident study report conducted in Britain (6). The study shows that two-third of all cycling accidents occur at or within 20 meters of a junction. Also it concludes that accidents are more where motor vehicle flows are high and junctions frequent. Severities of the accidents are highest where traffic speeds are high. Thus the safety parameters are framed such that the bicycle tracks that are being designed are kept away from junctions and roads as far as possible. The existing land use factor is taken care only for the buildings that are in the study area.

3.1.3 Determination of Evaluation Function

3.1.3.1 Accessibility Factor

Gradient – As cycling is primarily a form of physical exertion, the effort required to traverse from one point to another, not only in terms of distance, but also in terms of the steepness of the route is more important. Not only is traveling on steep routes strenuous on one's physique on the up-slope, it can also be potentially hazardous to the safety of both the cyclist and any nearby pedestrians when cycling down-slope. Adopting the AASHTO standards (7), the gradient of cycling routes are constrained to be 5%.

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Distance of the route – Bicycle travel is favorable for short trips and the present study design takes care of this factor as the O-D zones are selected at reasonable distance and each O-D zone is connected to the other to form a network within the campus.

3.1.3.2 Safety Factor

Distance from the road centers - Bicycle tracks with distance of at least 20 meters away from the main roads are generally thought to be safe from earlier studies (6). NUS road geometry is such that most of the major roads are approximately 10m wide. Considering the shoulder widths of 1.5 meters on each side, pedestrian paths of 1m on each side and a safety offset of 5 meters on each side together accounts to 25 meters which is now considered in analysis. This requirement has been modeled as a soft constraint, where its violation is to be minimized in the multi-objective evaluation function.

Distance from the road junctions – Same approach as of the distance to road centre constraints are assumed here. Very heavy cost is assumed for tracks that are at or within 25m of the road junctions. This is also based on the study conducted in Britain (6).

3.1.3.3 Existing Land Use Factor

Distance from the buildings **–** It is almost impossible for the bicycle tracks to pass through any major infrastructure and thus the buildings are masked in the analysis so that the track completely avoids all the built up areas.

3.2 GIS Modeling

As it is clear from figure 2, GIS modeling comes as the second stage in the proposed analysis methodology. This section describes the data sources used in the study, the map layers created based on the available data, generation of the weighted cost layer that is derived based on the evaluation constraints and finally the selection of bicycle tracks between the different origins - destinations.

3.2.1 Data Source

The contours, building and roads data of NUS campus were available in shape file format. The other essential data were digitized based on the available three base data source. These digitized data includes the boundary, which fixes the extent of the study area, the road center lines, the road junctions, and the origin & destination points. All these are put together into a campus geodatabase as shown in figure 4.

3.2.2 Map Preparation

Figure 5 shows the map preparation procedure from the data source based on the design criteria and the respective evaluation function.

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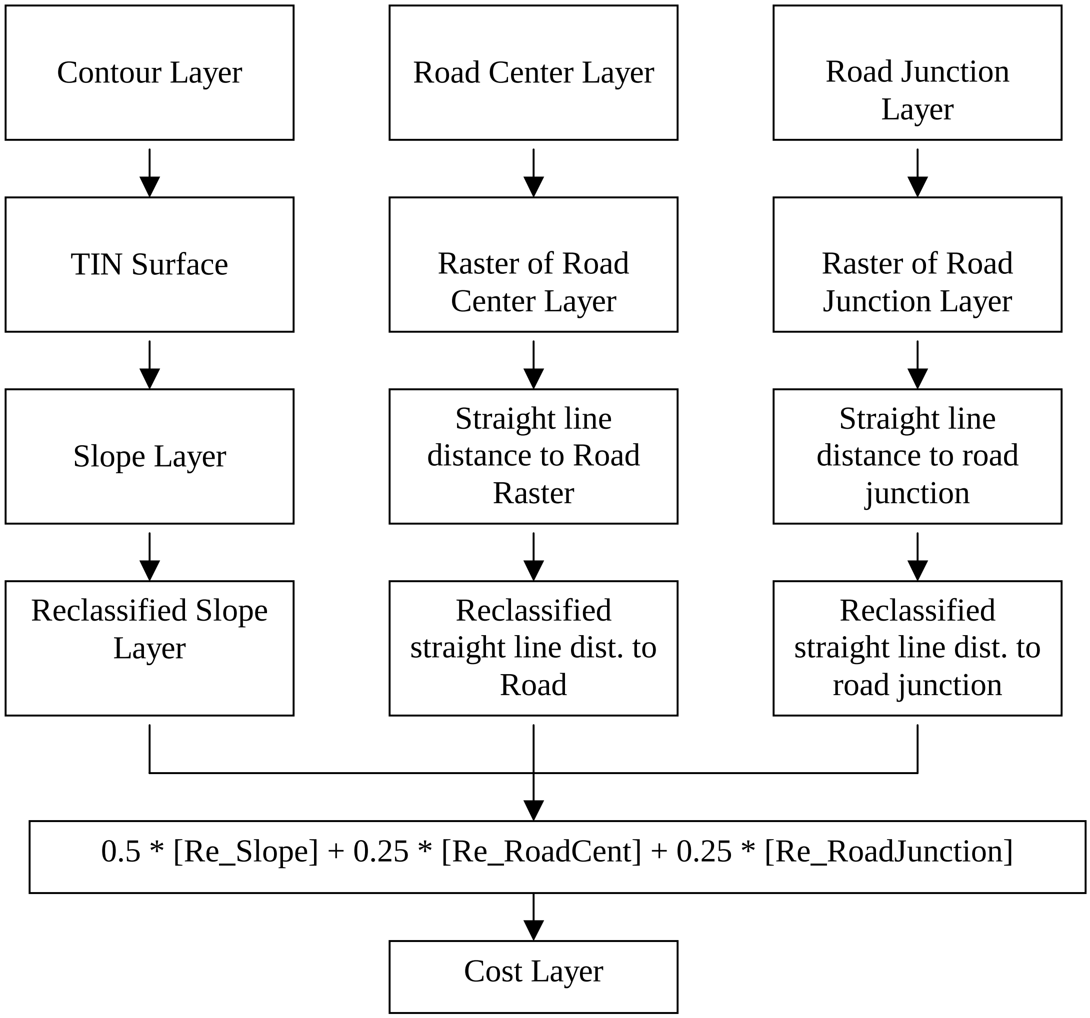

Figure 4. Data Source Representation

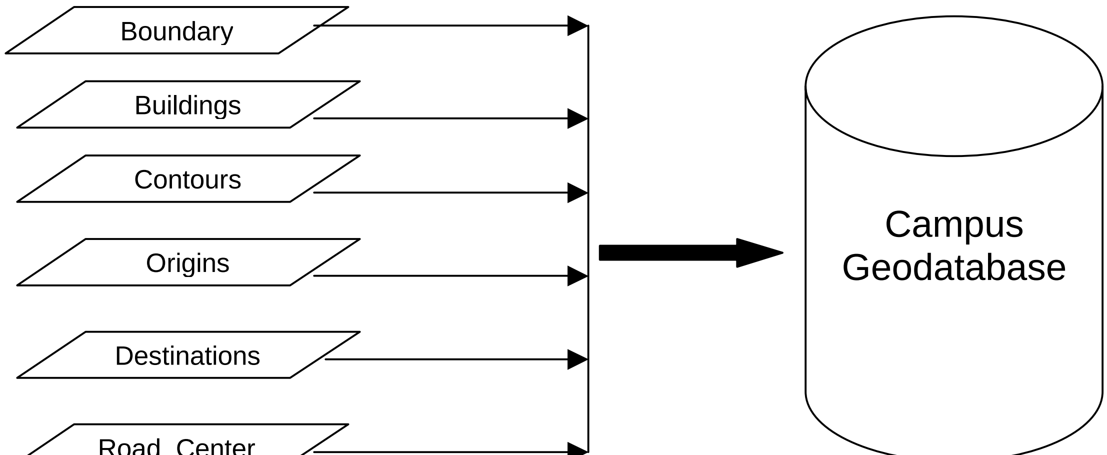

Figure 5. Flowchart showing the map preparation

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The flowchart shows the step-by-step generation of the final cost layer. Given the contour data of the NUS, a TIN surface is generated using 3D Analyst extension of the ArcGIS. With the TIN surface as input, a slope map is created using the slope function available in spatial analysis tool. With the given road data, a road center line data was digitized and was converted to a raster data as all the analysis done are raster based. Then we create a straight-line distance to the road raster data. Same approach is followed for the road junction data in creating a straight-line distance to the road junctions. Finally all the three layers i.e., slope, straight line distance to road raster and straight line distance to road junction are to be reclassified to a common scale ranging from 1 to 10 with the highest rank i.e. rank 10 getting a higher cost (penalty). A cost weighted approach is taken to prepare the cost layer giving 50% weightage to the accessibility factor and 50% weightage to the safety factor. 50% weightage of safety factor is again split up equally to the road centerline distance and road junction sub factors. Using the raster calculator the following equation is evaluated which generates the required cost layer.

0.5 * [Re_Slope] + 0.25 * [Re_RoadCent] + 0.25 * [Re_RoadJunction]

The raster analyses were performed based on the cell size set to 5m. Though reducing the cell size would generally give more accurate results but the given contour data with an interval of 5m would not eventually improve the results. Thus taking the hardware performance and considering the achievable degree of accuracy, the cell size for analysis was set to 5m.

The factors of accessibility and safety are considered in deriving the cost layer. The existing land use constraint is still to be included in the analysis. For this study, only the building areas are considered, that need to be avoided while performing spatial analysis to find feasible routes between an origin and destination. To accomplish this, a union operation is done on the boundary and the building layers which results in giving three outputs, one with the boundary layer with the building, building layer alone and the last one being the boundary layer without the buildings that needs to be exported separately and has to be used as a mask layer which completely avoids the built up areas of the campus.

3.2.3 Finding Feasible Bicycle Tracks

As all the assumed constraints are now transformed to the evaluation functions of GIS and with all the required cost maps being ready, the next step is to find the feasible bicycle paths between the origin and destinations. For this to be done, for each assumed origin points, a cost weighted distance and direction maps are created. With these cost distances and directions of the selected origin, the shorted path to the destination is selected using shortest path tool available in spatial analyst extension of ArcGIS.

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Figure 6. Bicycle tracks connecting different O-D's

3.3 Feasibility Study

To verify the feasibility of the routes derived, a field study was carried out to assess any constraint violation that may occur in practice. This field study is both imperative and pertinent since the data source was not complete with details of all the existing infrastructure. Also this need is heightened by the constant development of infrastructure within the campus. For illustration, the analysis of the bicycle route derived between a residential hall (Eusoff hall) to a faculty block (Law Link) is discussed.

Field study revealed certain hazardous section of the routs to the cyclists which was in the proximity of an existing bus stop. In this scenario, signposts have to be erected to mitigate the danger that is lurking. In addition, clear demarcations of the cycling route and adequate public education to the motorists have to be conducted. Also, the field study helped identifying parcels of land that can be used to construct parking facilities for the cyclists. These parcels of land are usually situated near the main buildings, yet away from the pedestrian crowd, making them the ideal location for the purpose of parking facilities for the cyclists.

4. Conclusions

This study suggests a procedure for using GIS to design bicycle routes within the university campus. The procedure includes determining the origin-destination points, defining pertinent physical constraints and evaluation function, developing the raw GIS layers into relevant raster layers, on which spatial analysis can be performed and verifying the aggregated results through a feasibility study in the form of a field investigation.

GIS is shown to be a very effective tool for the design of bicycle routes through the implementation of the procedure defined above in the context of NUS. Integration of data from various sources and capturing specific features crucial to cycling (e.g., major roads and buildings), is a task that is difficult without GIS. While this cannot be claimed as the most optimal

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cycling route to solve the traffic problem of NUS, this preliminary study established GIS as the prime analytical tool to be used, should a further, more detailed investigation ensues.

Further, the results from this study should be used with caution as the constraints and objective function were derived from research articles of foreign countries. The local perception of cycling as a form of alternative commuting means and the influencing factors to pick up cycling may differ significantly with those found in these research articles. Nevertheless, the procedure developed here should be helpful to further endeavors in considering the use of GIS technology for bicycle route planning.

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