A SPATIAL DECISION SUPPORT FRAMEWORK FOR PLANNING

Creating Tool-Chains for Organisational Teams

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Abstract. In practice, most planners do not make significant use of planning support systems. Although significant research has been conducted, the focus tends to be on supporting individual tasks, and the outcomes are often the development of new stand-alone tools that are difficult to integrate into existing workflows. The knowledge contribution in this paper focuses on developing a novel spatial decision support framework focusing on the workflows and tool-chains that span across different teams within an organisation, with varying skill sets and objectives. In the proposed framework, the core decision-making process uses set decision parameters that are combined using a weighted decision tree. The framework is evaluated by developing and testing tool-chains for a real-world land suitability case study. The tool-chain was implemented on top of a GIS platform.

Keywords. GIS SDSS PSS; Planning Automation; Geoprocessing; Data Analytics; Geoinformatics.

1. Overview

Although many Spatial Decision Support Systems (SDSS) and Planning Support Systems (PSS) exist, most planners do not make significant use of such systems in practice (Geertman & Stillwell 2003, 2009; Vonk 2006, Schilder 2016). The aim of the research is to explore an alternative approach to the effective use of PSS and SDSS, evaluated through a land suitability case study. The focus is on developing systems for large organisations with teams of diverse professionals with different expertise.

In order to improve the support function of PSS, a better conceptual and empirical understanding is required of the relation between planning tasks and PSS. Pelzer et al. (2015) discuss the concept of task-technology fit and PSS. They believe this concept can lead to a better understanding of the usefulness that is reachable by different planning support capabilities of a PSS for different tasks. However, PSS research typically focuses on supporting individual tasks, and the outcomes are often the development of new stand-alone tools that are difficult to integrate into existing workflows.

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In our research, we focus on workflows rather than individual tasks. Rather than developing stand-alone tools, we aim to support specific workflows by developing tool-chains on top of existing GIS frameworks. These workflows and tool-chains will typically span across different teams within the organisation, with varying skill sets and objectives. For example, a key challenge is a typical workflow in which planning decisions need to be made based on geoprocessed data (Zhu and Ferreira 2015). In such a workflow, the task for the GIS team involves analyzing large amounts of geospatial data, which is typically slow and requires a high level of technical knowledge. The task for planners focuses on decision making using that processed data, which must be interactive and requires domain knowledge. Finally, the results of the decisions need to be communicated by the managerial team.

This paper discusses how such planning tasks within an organisation can be linked into seamless workflows, supported by geospatial tool-chains. In order to demonstrate the proposed framework, a case-study on land suitability assessment and resource management is presented. The case study is based on workflows being developed by NUS in partnership with JTC Corporation, the lead agency in Singapore spearheading the planning, promotion and development of the industrial landscape.

The next section proposes geospatial tool-chains, and section 3 presents a case study focusing on land suitability assessment and resource management. Finally, section 4 draws conclusions and discusses directions for future research.

2. Geospatial Tool-Chains

In the proposed framework, the core decision-making process uses a set of decision parameters that are combined into a single metric. The parameters are first calculated based on the latest geospatial data. Once each parameter is calculated, overall fitness is then derived by using a weighted decision tree (Klosterman et al. 2018). These weights may vary depending on any kind of development for an assessment of land suitability. As a result, the weights must be user-defined.

For example, for supporting decisions related to land suitability, the parameters may include Land Area, Plot Ratio, Shape and Location. When making queries, a user can set the desired weightages for each of these parameters. This decision tree is then used to calculate assessments for all of the available plots (see Figure 1). Each plot is then given a percentage score, 100% being the maximum score for the specific query.

Such a decision-making process will be embedded within a broader workflow. The research proposed a workflow consisting of three main stages, with customized tools targeting different types of users with varying expertise. A definite workflow is proposed, consisting of three main stages: 1) Geoprocessing performed by the GIS team, 2) Interactive decision making performed by the planners, and 3) Communications performed by the managerial team (see Figure 2).

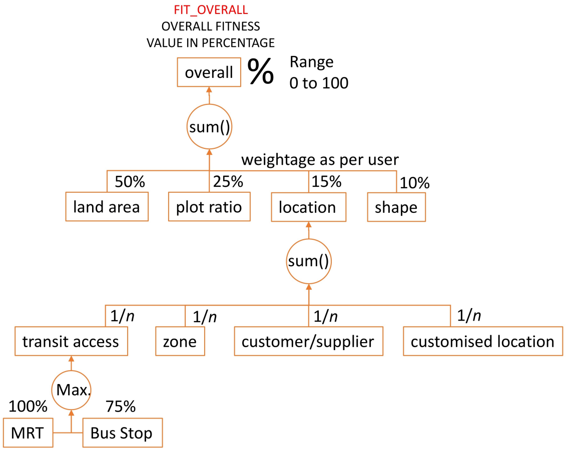


Figure 1. Decision tree.

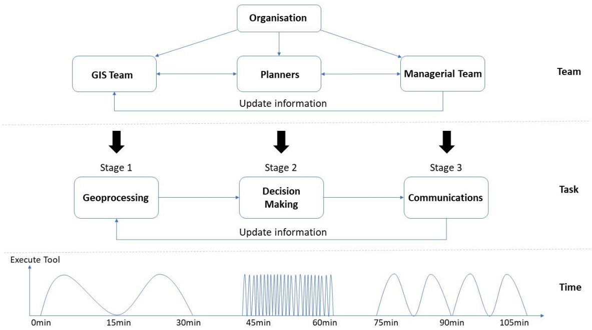


Figure 2. Tool-chain workflow.

2.1. THREE STAGES

Such planning workflows will typically involve different teams from varying departments in an organisation. In the proposed framework, a series of tools are developed for performing specific tasks in the workflow. In addition, an important issue is also the flow of data between specific tasks performed by different teams.

- Stage 1 - The *geoprocessing task* is performed by the GIS team, as this stage deals with compiling the latest data for the decision tree. The decision tree will need to be defined before this stage can be carried out.
- Stage 2 - The *decision making task* is performed by planners with specific domain skills in an organisation. This process may include extensive customisation and exploration of the decision-tree weights.
- Stage 3 - The *communications task* is performed by the managerial team, creating reports to be presented and deployed to a land developer. If the requirements cannot be met, the process will usually go back to stage 2.

The geoprocessing task handled by the GIS Team is the slowest task to execute, but is executed infrequently and does not need to be interactive. This task results in data sets that are then consumed by the decision making task. This task must be fast and interactive so that the planners are able to iteratively explore many alternative parcels. Finally, the communications task will consume the data sets created by the decision making task, and produce a set of final reports for presentation to the land developer.

In this division of labour, the geoprocessing task is only executed when new input data is added to the GIS database, such as changes to the masterplans and new land use information. The decision making-task, on the other hand, can be executed multiple times without having to re-execute the time-consuming geoprocessing task. If the requirements cannot be met, then the communications task can loop back to the decision-making task to consider alternative plots. The formalisation of these three stages makes the overall decision-making logic more transparent and evidence-based.

3. Land Suitability Case Study

The case study focuses on a land suitability assessment process for different land use developments using open-data available (see Figure 3). This process involves land developers looking for real estate developments.

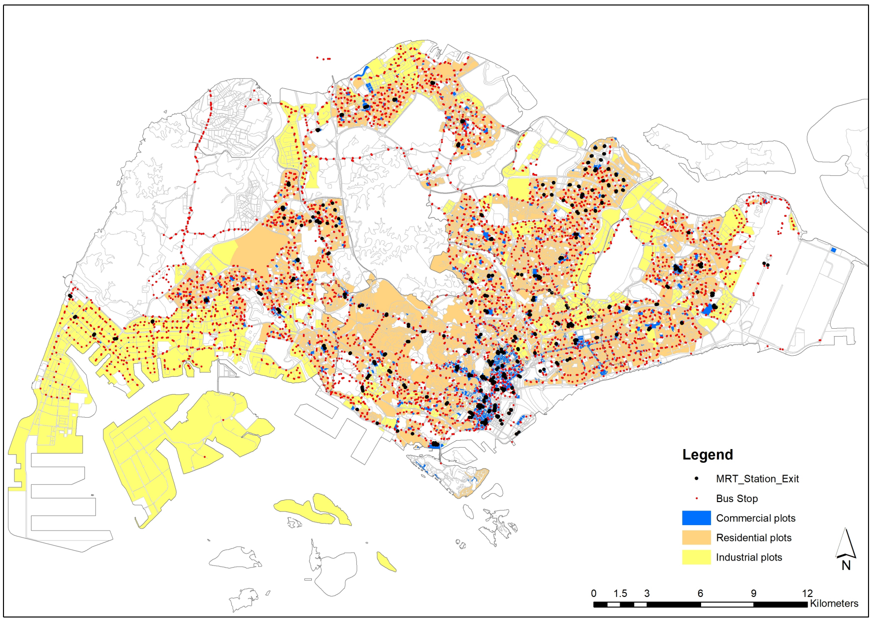


Figure 3. Plots with different land uses and public transit access in Singapore (open data source: data.gov.sg & mytransport.sg).

These land developers will approach organisations and will submit a request for available land parcels that meet specified requirements. Through the land suitability assessment process, the organisation will select appropriate land parcels to present to the land developers. The land parcels are selected based on the requirements, taking into account planning regulations and other long term strategic planning goals. The process iterates back and forth filtering land parcels for different requirements and constraints in parallel.

A tool-chain has been developed and tested to semi-automate the land suitability assessment process (see Figure 4). The tool-chain combines various requirements and constraints into a single integrated query and helps planners to select land parcels based on geospatial data analysis

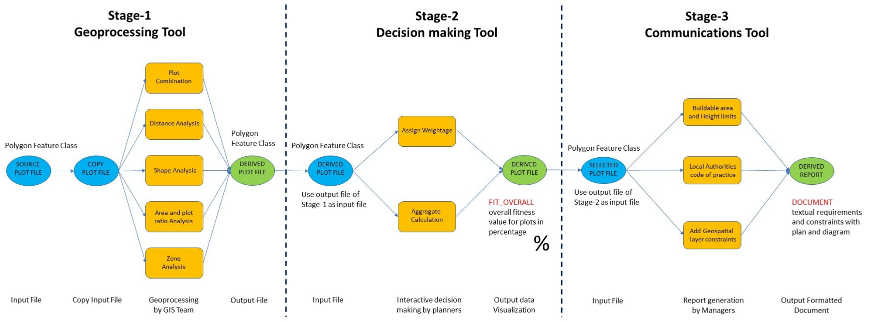


Figure 4. The land suitability assessment tool-chain with three stages. .

The Land Suitability tool-chain allows the planners to interactively query and interrogate an integrated database of land parcel information. The decision-making tool also provides the ability to customise the land query based on specific land developer requests.

The tools chains operate on GIS datasets called *feature classes*. Feature classes are homogeneous collections of common features, each having the same spatial representation, such as points, lines, or polygons, and a common set of attribute columns. Feature classes are stored in geodatabase files (.gdb). Geodatabase files were used due to their compact and efficient nature.

3.1. STAGE 1: GEOPROCESSING TOOL

The Geoprocessing Tool calculates spatial data required for the analysis performed with the Decision-Making Tool.

The main input to the Geoprocessing Tool consists of a feature class containing a set of land parcel polygons, referred to as *plots*. The results of the Geoprocessing Tool are added to this feature class as additional attributes. Other feature classes required by the tool include the masterplan with Gross Plot Ratio (GPR) information and public transit information (for buses and Mass Rapid Transit -MRT).

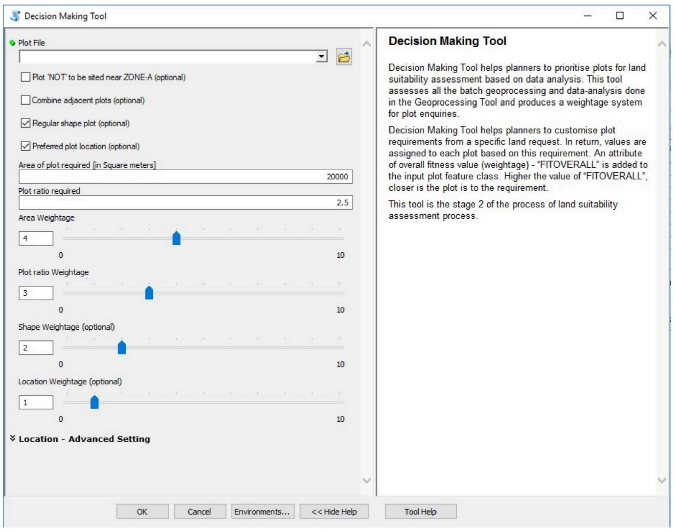
The types of analysis include shape analysis, regional or zone analysis, next to a specific customer/supplier, and additionally customised location preferences.

Additional feature classes may also be required depending on the types of analysis being performed.

3.2. STAGE 2: DECISION-MAKING TOOL

The Decision-Making Tool allows planners to interactively and iteratively assess available plots by setting the requirements and defining parameter weightages (see Figure 5).

The planners use the tool to enter the requirements from the land request and the weightages for the decision tree parameters. The tool then assesses the plot, and assigns an overall fitness value to each plot, normalised to the range of 0 to 100%. The fitness value is added as an additional attribute to the feature class. Plots are then ranked, with the plots with higher fitness being more suitable. In order to visualise this data, a heatmap of the plot fitness values is automatically generated. The planner can then review the plots with high fitness values and either select a preferred plot make, or adjust the parameter weightages and run a new query.



Plot File

☐ Plot 'NOT' to be sited near ZONE-A (optional)

☐ Combine adjacent plots (optional)

☑ Regular shape plot (optional)

☑ Preferred plot location (optional)

Area of plot required [in Square meters]: 20000

Plot ratio required: 2.5

Area Weightage: 4 (0–10)

Plot ratio Weightage: 3 (0–10)

Shape Weightage (optional): 2 (0–10)

Location Weightage (optional): 1 (0–10)

Location - Advanced Setting

Decision Making Tool

Decision Making Tool helps planners to prioritise plots for land suitability assessment based on data analysis. This tool assesses all the batch geoprocessing and data-analysis done in the Geoprocessing Tool and produces a weightage system for plot enquiries.

Decision Making Tool helps planners to customise plot requirements from a specific land request. In return, values are assigned to each plot based on this requirement. An attribute of overall fitness value (weightage) - "FITOVERALL" is added to the input plot feature class. Higher the value of "FITOVERALL", closer is the plot is to the requirement.

This tool is the stage 2 of the process of land suitability assessment process.

Figure 5. User interface of the Decision-Making Tool in ArcGIS.

3.3. STAGE 3: COMMUNICATIONS TOOL

The Communications Tool helps the managerial team to check various additional requirements and constraints based on the local authorities code of practices for a selected plot.

The tool checks two key constraints. The first constraint to be checked is the effective buildable area of the selected plot. The buildable area is calculated taking into account various no-build zones. These include no-build zones imposed by adjacent roads, with different road categories having different offsets. The second constraint to be checked is the permissible building height of the selected plot. The building height is constrained by limits imposed by various government agencies. The maximum floor area for the development is first calculated based on the plot area and Gross Plot Ratio (GPR), which is derived from the Masterplan (2014). The building height is then calculated by applying a set of predefined rules for the selected building typology for the development of the buildable area of the plot. This building height is then checked against the height limits for the plot.

The tool also automatically generates a formatted report (in .docx format) that summarises all relevant information about the selected plot. The information in the report includes text and tables describing the key data for the selected plot, as well as all the regulations and codes of practice that are applicable. The report also includes a formatted plan diagram of the selected plot, showing graphical representations of some of the key constraints (see Figure 6). This report can be used for effective communication to the land developers or to officially register the chosen plot for tenure.

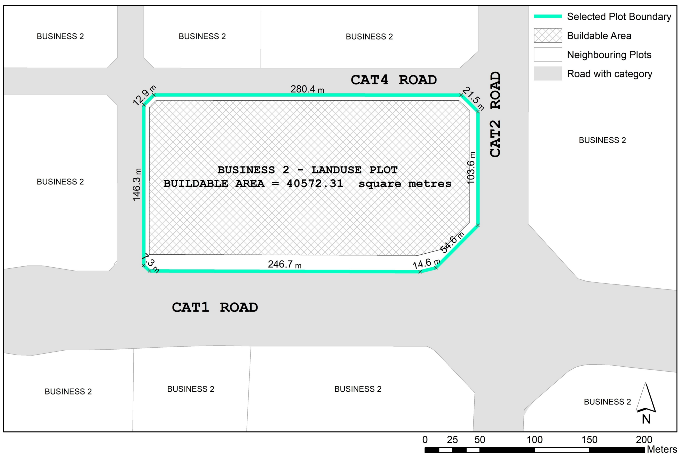


Figure 6. Result of Communications tool: plot plan showing calculated buildable area.

3.4. IMPLEMENTATION

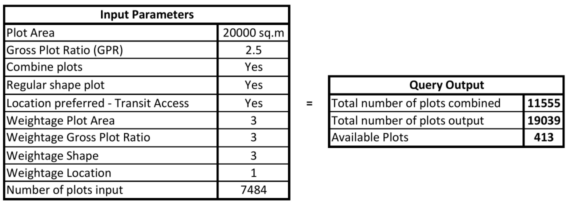
The tool-chain has been implemented within the ArcGIS platform. This platform was chosen due to the fact that it is already commonly used within planning organisations, making tool adaptation and utilization easier. Our initial attempts to create tool-chains were developed using the ModelBuilder visual programming environment within ArcGIS. However, the programming paradigm lacked scalability and as a result, models quickly became very complex and difficult to understand. In the final version, all tools were implemented as Python tool scripts.

The three tools all include graphical user interfaces (GUIs) to allow users to enter the parameters, with built-in validation and error checking. The tools can be easily shared and deployed, becoming an integral part of the everyday working environment. Documentation for each tool has also been developed, which can be accessed in the same way as the documentation for system tools (Zandbergen 2013). All three tools automatically filter out invalid data types and field names and will flag errors for the user, giving feedback and warnings.

In addition, all the output data of the three tools are saved inside geodatabase files (.gdb) located in a shared workspace in a network drive. This allows teams in the organisation to easily work together, linking and sharing data in a seamless way.

3.5. RESULTS

The tool-chain has been tested with a wide variety of queries using open data collected for plots in Singapore. As an example, a query for an industrial plot is presented. The query specifies the required plot area, GPR, plot shape, location, together with a set of decision tree weights. The results of the query are described below (see Figure 7 & 8).



Input Parameters	
Plot Area	20000 sq.m
Gross Plot Ratio (GPR)	2.5
Combine plots	Yes
Regular shape plot	Yes
Location preferred - Transit Access	Yes
Weightage Plot Area	3
Weightage Gross Plot Ratio	3
Weightage Shape	3
Weightage Location	1
Number of plots input	7484

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Query Output	
Total number of plots combined	**11555**
Total number of plots output	**19039**
Available Plots	**413**

Figure 7. Plot query table.

The stage-1 Geoprocessing Tool was tested with a feature class containing 111,525 plot polygons. The time taken to execute the Tool was around 30 minutes. Stage-1 found 7484 industrial plots and created 11,555 second-order plot combinations. This resulted in a total of 19,039 plots available for query. The stage-2 Decision-Making Tool then filters these plots based on a set of specified weights and other requirements, resulting in a total of 413 available plots. The decision maker can then select the most suitable plot. Finally, the stage-3 Communications Tool can then be used to check additional requirements and constraints, and to generate a report.

At the end of stage-3, the registration of the selected plot is fed back into the database. This becomes a part of an organisational process, as the managerial team informs the GIS Team of these updates, thereby closing the geospatial data loop. Within the framework, the system, organisation, and its members go hand-in-hand in maintaining and manipulating geospatial data.

The tool-chain is currently limited to a specific number of input parameters. If additional parameters need to be added, then these can be added. This would require both the geospatial data schema and the Python script to be updated. However, such modifications may be difficult for users who are not familiar with Python programming and who do not have knowledge of the various tool templates defined within ArcGIS. Approaches are being investigated that are more flexible and modular, allowing additional parameters to be defined without requiring programming.

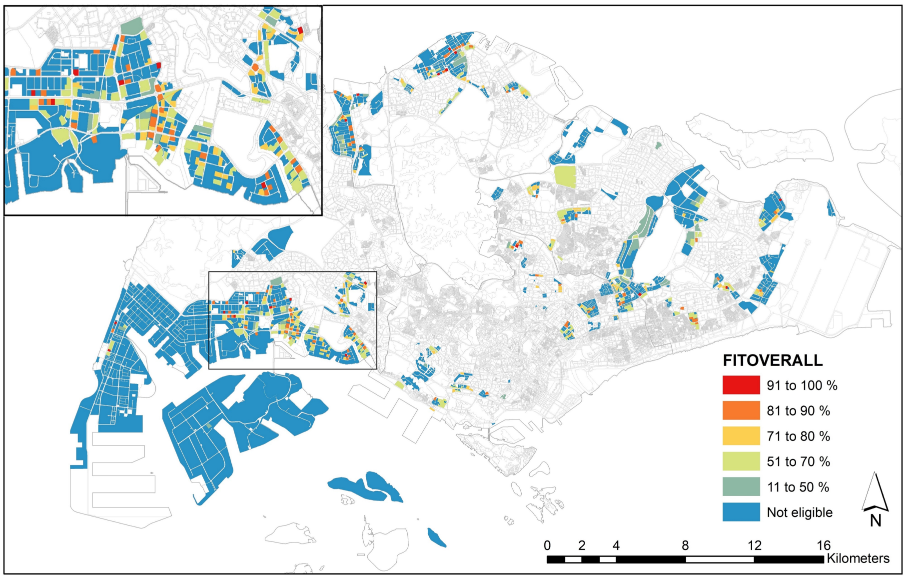

Figure 8. The result of land suitability assessment query using tool-chains.

4. Discussion

The paper has presented a spatial decision support framework focusing on the workflows that span across different teams within the organisation, with varying skill sets and objectives. A tool-chain was implemented on top of ArcGIS, supporting decision making for planners. In the proposed framework, the core decision-making process requires set decision parameters that need to be combined using a weighted decision tree (Klosterman et al. 2018).

A case-study demonstration is presented on land suitability assessment and resource management. In the decision-making stage, the planners assign priorities to different types of spatial analysis and filter land parcels. This tool-chain helps planners to select plots based on geospatial data analysis. The demonstration shows how planning tasks within an organisation can be linked to seamless workflows.

The broader aim of this research is to develop a practice-orientated approach to creating Planning Support Systems. A key problem with existing SPSS and PSS systems is that they are developed in isolation of the workflows within organisations. This results in a lack of synergy between the tools and the workflows in practice. This research started by first mapping out end-to-end workflows that existed within the organisation. Based on these workflows, a set of modular and flexible tool-chains were then developed on top of the existing GIS infrastructure already being used within the organisation. This approach ensures that these tools and system are well aligned with the workflows, result in effective usage. Future research will apply the same overall approach to other planning workflows, including long-term planning projections taking into account various dynamic urban and city-scale constraints.

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