

Integration of Raster-Based GIS and System Dynamics and Its Application

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1. Introduction to the Problem

At present, Geographical Information Systems (GIS) and System Dynamics (SD) can still be considered as scientific tools in the developing stage which are gaining popularity because of their utility in their own separate fields. GIS deals with the data, their position in a coordinate system, their attributes, and their spatial interrelation with each other, while System Dynamics is used to understand problems which are dynamic (involve quantities which change over time), and also involves the notion of feedback.

GIS and system dynamics packages have their own strengths and weaknesses, as summarized in Table 1.1.

Table 1.1 Comparison between GIS and SD Packages

	GIS	System Dynamics
GIS capability - position with respect to a known coordinate system - attributes of each point in the coordinate system - spatial interrelations with each other - producing 'thematic' map	Yes. Yes. Yes. Yes.	Yes, can be done using 'array' in Dynamo III, with <u>severe limitation</u> . Yes. Yes. In a certain way. No.
Modelling capability - repetitive calculation - dynamic - feedback - producing graphs of any variable over time	No. (can be done manually) No. (can be done manually) No. No.	Yes. Yes. Yes. Yes.

Even though Dynamo III can be used for building the model with spatial interrelations by using the 'array' functions to store the values of each base map, but it does have some disadvantages. These disadvantages are: 1) the difficulty in data entering process, which has to be done manually (cannot be read from the external files), 2) the lack of flexibility in making changes or corrections, and 3) the difficulty in modelling the interactions between neighboring cells.

In summary, GIS's spatial features are not made for analyzing systems which show changes over time, thus require repetitive computation, while System Dynamics is not made for dealing with spatial relationships. This, of course, creates a gap between the two

methods, which limits the study and in-depth understanding of any system falling inside this gap, most as so physical/cultural system.

2. Objectives of the Study and Scope

The objective of this research work is to demonstrate the integration of System Dynamics (SD) and Geographic Information System (GIS). To do this, one 'HyperCard' and one 'SuperCard' program were developed, having the capability of dynamically simulating a particular model through 'STELLA' and displaying outputs in GIS's raster format.

The program is expected to be useful in; (1) gaining insight and understanding of a relationship between SD and GIS, (2) analyzing a real world problem, for example, model-based policy analyses, which involve the use of the model to help investigate why particular policies have the effects they do and to identify policies that can be implemented to improve the problematic behavior of the real system, and (3) assisting in better and improved decision making in natural resource management, to promote economic growth and better living conditions.

This project is hoped to fit itself in INRDM's area of interest (Lukens 1988), which are (1) the information technology theory and practice applied to natural resources assessment, planning, and monitoring, (2) studies dealing with the principles and practice of integrated land-use planning and natural resources management, and (3) human relations skills and procedures necessary for multidisciplinary team planning, including rational procedures for analyzing problems and making decisions.

The scope of this study is restricted to proving that GIS-SD interface is possible, with suggestions for various applications. It, by no means, aims to develop a complete or perfect model for prediction of land use change. The models, which were built and is referred to in this report, serve the sole purpose of proving the new concept and also demonstrating how the developed program works.

3. Methodology

To demonstrate the integration of GIS and SD, a program was developed to link these two fields together. This following section summarizes the general structure of the program, its capabilities, and its working.

3.1 Technical Data of the Program

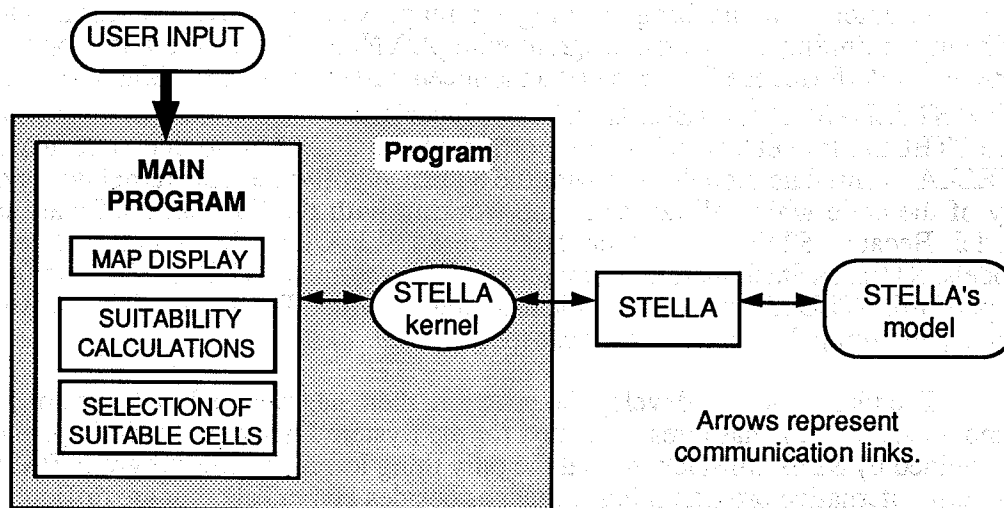
Hardware	:	Macintosh IIci, 4 MB RAM, 80 MB HD
Software	:	STELLA for business, STELLAStack, SuperCard, HyperCard
Data Structure	:	Raster-based GIS

3.2 Program's Structure

The general structure of the program is illustrated here. The communication link between HyperCard or SuperCard and STELLA, is in the form of a 'resource'¹ which has to be 'loaded' into HyperCard's or SuperCard's program. This resource, called 'the STELLA kernel', is an XCMD (External Command) written by High Performance

¹ Resources are the traditional building blocks of all Macintosh programs.

Systems, Inc. (developer of STELLA). It is a portion of the STELLA source code which enable STELLA to simulate models built with the STELLA software.



3.3 Design Capability of the Program

The program as designed has the following capabilities:

- a) GIS capabilities, including data input, data storage, data manipulation & analysis (mainly concentrated on calculations of suitability values for the simulation), and data reporting.
- b) Ability to simulate behavior using a System Dynamics model (STELLA), and display the spatial consequences of the output in the form of a GIS map,

3.4 Program's Limitations

- a) Ten map categories are allowed in one map.
- b) Up to ten base maps can be displayed (in 'Display' stack).
- c) In its present state, the values transferred between STELLA and the program cannot be changed during simulation.
- d) The maximum size of the map is 180 rows by 150 column.
- e) The output maps can be displayed on the screen only in the 'Display' stack. Printing hard copies requires color laser printers, which are currently available in the market. Negatives or slides can be taken directly from the screen with some distortion, or they can be made using special hardware. The details of these hardware can be found in the magazines for Macintosh computers, such as MacUser or MacWorld.

These limitations are considered to be temporary. This is because more functions and calculation routines can always be developed and added to the program, if time permits.

4. Program's Development and the Models Used

In the beginning of the project, the hardware chosen was the NEC' APC IV microcomputer, and the programming language was TURBO PASCAL. Due to the difficulty in linking the written program with pDYNAMO, the idea was dropped. By that time, High Performance Systems had announced a new product for Macintosh Computers called STELLAStack². STELLAStack is a HyperCard's stack which contains what's called "the STELLA kernel", which is the portion of the STELLA source code which allows STELLA to simulate models built with the STELLA software. The kernel does not contain any of the code which allows someone working with the STELLA software to build a model. Because STELLAStack contains the STELLA kernel, it can simulate STELLA models. STELLAStack therefore provides a way to simulate STELLA models from within HyperCard. STELLAStack communicates directly with STELLA models, it also can send data to, and bring data back from, these models.

The idea of how to develop the program, then, has changed to the use of Macintosh computers. STELLA has already existed for the System Dynamics modelling, and the link is provided by STELLAStack, so that the only thing left is the GIS program. PASCAL and C as also alternative programming languages besides HyperTalk, but are difficult to link to STELLA. The final decision was to write the program in HyperTalk.

The first test-SD model created is called 'Farm'. It is a simple model, built for the purpose of checking the program's bugs and the overall performance. This model is a made-up model, having an area of only 16 x 16 cells (a total of 256 cells). The use of HyperCard limited the display of maps in black-and-white and tones and patterns were used to improve the readability of the maps. The program uses three maps; land use, slope, and soil to calculate the suitability scores. The 'Farm' model provides the degree of change happening to farm and forest area, and the program selects the most suitable cells based on the computed scores. The STELLA program available at that time was version 1.0 and it lacked many functions which are crucial to the development of the research.

The second SD model used for testing is the 'BoomTown' model³. It is an already-developed model, which is generally accepted. The maps used in the simulation were made-up. The size of these maps were increased to 30 x 30 cells. SuperCard was used instead of HyperCard, which allows the use of colors for map display. The old black-and-white display imposes a limitation on the resolution of the map (the size of one cell). The greater the resolution, the more difficult it is for the human eye to differentiate the cells. By using colors, a greater number of map categories can be included. The program and the model were seen to perform well.

Finally, the third model is developed. Modelling data was collected from Statistics and Research Division, Technical Department of Tourism Authority of Thailand, the Department of Town and Country Planning (DTCP), and other places. The purpose of using this Pattaya model is just to suggest and demonstrate the applicability of a more complex model.

At the present, the program was divided into two programs to allow the increase of speed. The 'DGIS' program was written using HyperCard, has the ability to control the

² See the descriptions of all words related to STELLA and Macintosh computers in Appendix A.

³ The model was provided to the author by the courtesy of Dr. Khalid Saeed, Industrial Engineering Department, AIT.

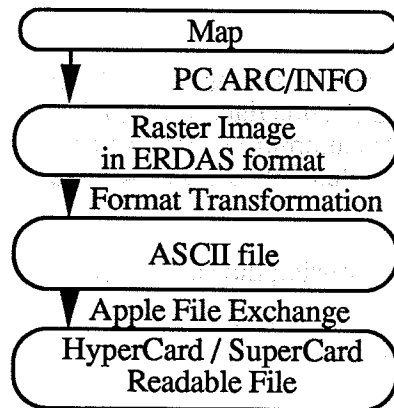
simulation. This program runs only in black-and-white. On the other hand, the SuperCard application called 'Display' is used for viewing the base maps and the output maps in color.

4.1 Pattaya: The Study Area

Pattaya is 147 kilometers southeast of Bangkok and is Asia's premier beach resort. It can be reached in a 2-hour drive along Sukhumwit Highway (Highway No.3) via Bang Na, Bang Pakong, Chon Buri and Siracha.

Pattaya city was chosen because: 1) Pattaya is a relatively small city as compared to Bangkok, which reduces the size of the area that has to be handled, and allows the use of a higher map resolution, 2) it is one of the fastest growing cities in Thailand, showing marked changes in land use pattern within a short period of time, and 3) it is easy to collect data because of the short travel distance from Bangkok and AIT.

4.2 Preparation of Base Maps



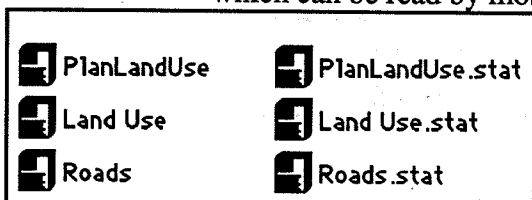
Three base maps were received from the Department of Town and Country Planning (DTCP). Pattaya's 1986 land use map, planned land use map 1986-1991, and road map were digitized using PC ARC/INFO. The spatial resolution of these maps is approximately 100 m. by 100 m., resulting in a 91x154 cell map. Higher resolution may be used in the future. The diagram shows the process of preparing the data for the program.

4.3 Running Steps

4.3.1 Preparation of input maps

The input maps were prepared by the following procedures.

- The map sheets were digitized by ARC/INFO and then rasterized into binary ASCII-format files. The data in these files was in the form of one long ERDAS format files, which were then connected into continuous record.
- The files were transformed into another format, in which the data was divided into records. The number of records is the number of rows in the map, and the number of fields in each record corresponds to the number of columns.
- The data files were transformed to Macintosh computer, using the program called 'Apple File Exchange'. The files are saved in Macintosh format which can be read by most of the Mac's program.



There are also other ways to prepare the data files for this program. They can be created by other means as long as they have the format which can be read by the program (Macintosh's ASCII).

4.3.2 Preparation of weight & scores file (.ws file)

These files will be used for the suitability calculation for each category of the file (map) under simulation. The format of '.ws' data file is given in Appendix D - the User's Manual, in the doctoral paper. Because each category requires its own '.ws' file, there will be as many files as the number of categories.

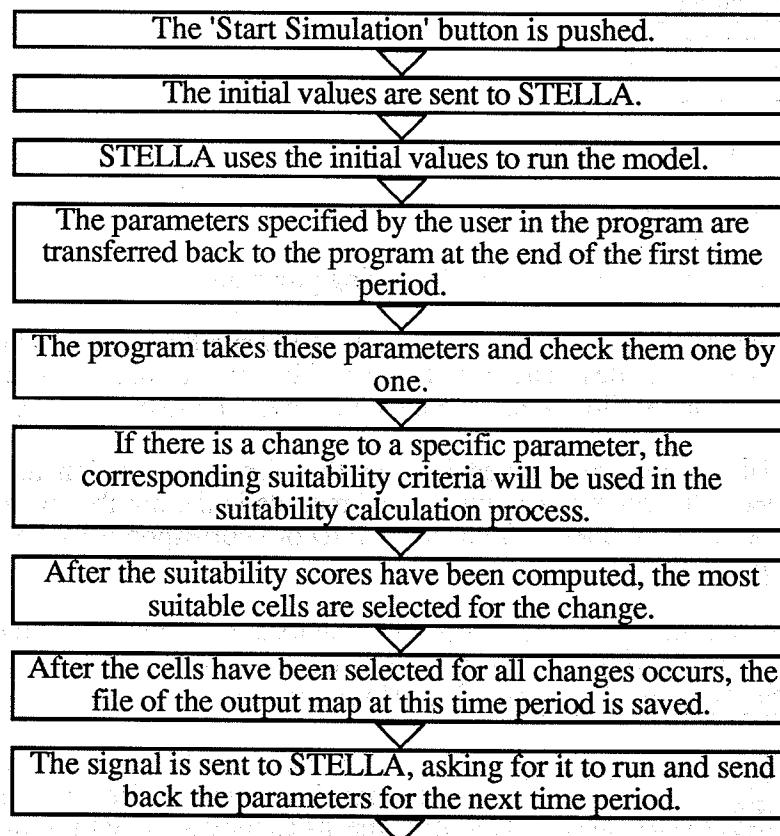
4.3.3 Specification of the simulated file, STELLA's model, initial values, data flows, and run options

The name of the map's file to be simulated and the name of STELLA's model are specified in the fields in 'Control Room' card of 'DGIS' stack. The initial values are entered into 'Data to Stella' field. List of factors bringing back from STELLA is put into the 'Data from Stella' field. Run options can also be set. See more details in Appendix D - The User's Manual, in the doctoral paper.

4.3.4 Starting simulation

After all necessary information is entered, the simulation can be started by clicking the button labelled 'Start Simulation' of 'DGIS' card. The program sends data to STELLA program, brings the simulated values back, computes appropriate suitability scores, selects the most suitable cells, and then, saves the changed map as new file. This process will be repeated for the user-specified period.

The following describes briefly the steps the program takes during the simulation.



The program keeps on running through this loop for the number of times specified by the user.

The simulation is terminated.

5. Conclusion

This research has demonstrated that integrating SD and GIS is possible. This will prove to be another valuable step in the science of simulation and prediction of behavior of any dynamic spatial GIS system.

The concept of the integration is yet in the infancy stage. The flexibility of the structure of HyperCard's and SuperCard's programs with their OOP concept (Object Oriented Programming) are highly valuable in the development of the program. Further integration package with remote sensing field or other related sciences may not be only a dream, but a reality, in the near future.

6. References

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