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OPSALC: AN OPERATIONS PLANNING SYSTEM FOR AUTONOMOUS LANDFILL COMPACTION

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Abstract:

The construction workers and operators associated with the sanitary waste landfilling operation are at high health risks because of constant exposure to harmful solids and gases. Automation of spreading and compacting processes during landfilling operation can result in improved safety due to reduction in exposure of workers to harmful environment. This paper describes a software system developed to assist: (1) design of landfill cells and (2) generation of area-covering path plan for spreading and compaction processes during a landfilling operation. A given landfill site can be partitioned into 3-D cells using a probabilistic model for waste generation that takes into account population of the community served by the landfill. Partitioning of landfill is performed by employing a recursive spatial decomposition technique. During the decomposition process, a gradient in the range of 1:3 to 1:2 is maintained for each cell. A recursive sub-division of each cell into *monominoes* facilitates the system to automatically deal with any deviation in the actual volume of waste generated on a particular day to the probabilistic value of waste generation. The system is implemented using PHIGS graphics standard and MOTIF toolkit with C-program binding.

1. INTRODUCTION

Land disposal in the form of sanitary landfill has proved to be the most economical method for the disposal of solid waste. A landfill can be considered as a biological-reactor of organic matter that produces leachate and gases [1]. As a result of decomposition and degradation of the waste material toxic liquid and hazardous gases originate from the landfill site. Constant exposure to such dangerous material may cause long-term health damage to manual workers/operators involved in the landfilling operation.

Automating the construction processes of the landfilling operation offers substantial benefits in terms of not only safety but economy. High wages and insurance premiums resulting from constant exposure of workers to dangerous materials can be reduced by automating certain processes during landfilling operations. However, automation of processes such as spreading and compaction of waste and cover material in a landfill site requires an efficient operations planning system to generate an area-covering path that facilitates autonomous movement of compactors. This paper describes a software system developed for assisting design of landfill cells and generating area covering path for an autonomous compactor.

2. CHARACTERISTICS OF LANDFILL OPERATIONS

The design, construction, and operation of waste landfill sites must be carefully performed because of the following factors: (1) contamination of local groundwater, (2) development of odors, and (3) structural stability [2]. During the landfilling operation, the waste is delivered and dumped to the site by dump trucks. Dumped waste is then spread and compacted by the landfill compactor into thin layers within a small area called *cell*. The compacted waste are covered with a 6- to 12-in layer of cover material at the end of each working day and compacted to a high-density. Several cells that have same lift height constitute a level. Finally, when a number of levels have been constructed and the top elevation of landfill reaches the final grade, a 2 ft thick layer of final cover material is placed over the top and compacted to a high-density.

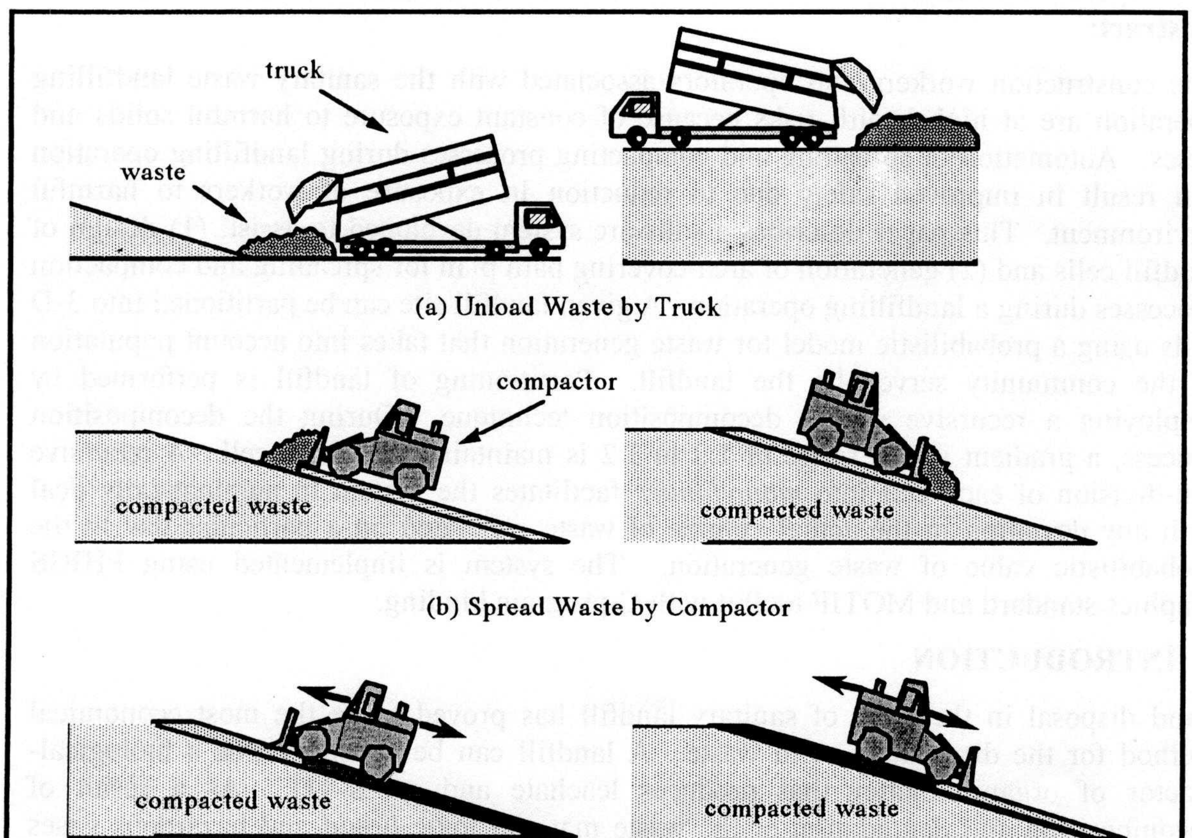

Figure 1: Placement and Compaction in a Landfilling Operation

In general, the most economical operation will result when the dimensions of the cell is maintained such that the length and width of the cell are about equal [3]. The overall operation of the landfill will benefit by restricting the depth of each cell to approximately 6 to 10 ft. Due to the design requirements, of keeping the cover material volume to a minimum and deposing of as much waste as possible, adequate and economic compaction of the waste can be achieved if the material is spread in thin layers and worked with a slope maintained at a gradient of 1:2 to 1:3.

As depicted in Figure 1, there are two principal methods to perform placement and compaction processes in a landfilling operation: (1) unloading solid waste at the toe of the slope, spreading them in a 2 ft deep layer and then compacting over this layer from the bottom of a working slope to its top and (2) unloading solid waste at the top of the slope, spreading and compacting it from the slope top to the bottom.

3. PROGRAMMING PLATFORM

The Programmer's Hierarchical Interactive Graphics System (PHIGS) is a X-window-based computer-graphic functional interface standard approved by International Organization for Standardization (ISO). PHIGS offers portability to many different computers using different operating systems and window systems [4].

The MOTIF toolkit library, designed by the Open Software Foundation (OSF), offers C and C++ functions to develop graphical user interface (GUI) for application programs. The MOTIF toolkit is based on the X Toolkit Intrinsics (Xt) of the X-window system and supports an object-oriented programming approach to create interfacing objects such as windows, scroll bars, and menus [5].

PHIGS provides the best environment for hierarchical graphic models that allow an application programmer to describe a graphic model without having to deal with the hardware details for producing the model on a display device, whereas, MOTIF offers functions to produce user-friendly interfacing objects such as windows, menus and icons that are independent of graphical primitives. Therefore, PHIGS library was utilized for graphical input and output and MOTIF toolkit was employed to develop menus and dialogue boxes.

4. SYSTEM DESCRIPTION

The operations planning system is capable of assisting cell design process and compaction process planning for sanitary waste landfill sites. The OPSALC supports geometric design of landfill cells by generating 3-D configurations of cells for a given input pertaining to : (1) geometric configuration of landfill site, (2) limiting slope for each cell, and (3) population of the community served by the landfill site. The size of each cell is determined using a probabilistic model for waste generation developed by Tchobanoglous et al. [2]. Optimization of cell design process is possible through investigation of cell configurations for various different slopes in the range of 1:3 to 1:2.

Figure 2 shows a typical screen configuration of the OPSALC during the input stage. Multiple-views of the landfill site can be tiled together by varying the orientation of the *view reference planes* for the tiled windows. The example screen shown in Figure 2 depicts a plan-view, an elevation, a front-view, and an isometric view of the landfill site at the same time. Altering the geometric configuration to any one of these view will automatically update the remaining three views.

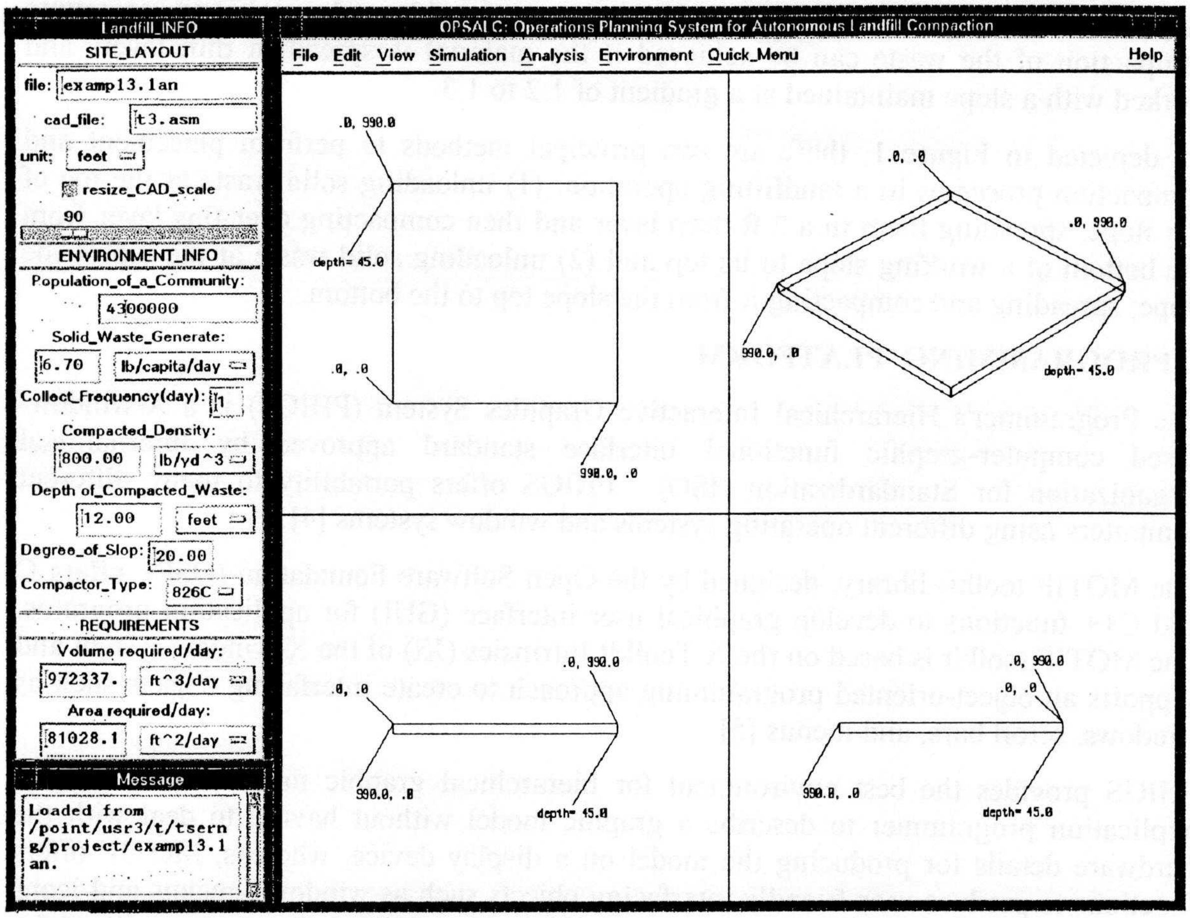

Figure 2: Screen Configuration During Input Stage

.Graphical information pertaining to a landfill site created using any other commercial software package, that supports ASM graphical file exchange format, can be loaded easily using the "Open" option under "File" menu of the OPSALC. Upon completing the transfer of graphical information from another software package a message box will appear at the bottom-left corner of the screen, to indicate the successful transfer of information, as shown in the Figure 2.

After obtaining the input pertaining to the landfill site, a recursive spatial decomposition procedure can be initiated by selecting the *Decomposition* item in the *Analysis* menu. The recursive decomposition procedure will result in partitioning of the landfill site into *cells* based-on the probabilistic model for the waste generation. Figure 3 shows an example of the lower most layer of a landfill site, serving a community of 4.3 million people, partitioned into 9 cells. Size of each cell confirms to the compacted volume of the estimated waste generated per day. The compacted density of waste used in this volume calculation conforms to the U.S. government regulations [2].

The spreading and compaction of waste typically occurs in smaller portions of a *cell* called *monominoes*. Partitioning of each *cell* into *monominoes* is performed by another recursive spatial decomposition process initiated by selecting *Monominoes* item from the *Analysis* menu. Each *cell* in Figure 3 is further decomposed into 16 monominoes using a variant of the quadtree data structure. Partitioning of each *cell* into *monominoes* enables application of direction-parallel path planning technique for autonomous motion of a compactor. The Area-covering path planning approach employed by this system optimizes the following two functions: (1) the size of a *monomino* based on population and (2) the overlap among adjacent strips during a direction-parallel path. The optimation of overlap takes into account factors such as compactor width, minimum turn radius, and hardware inaccuracies. The dual optimization problem is solved iteratively using an alternating approach. The decomposition technique employed during the development of the system enables modification of the autonomous operations plan when the size of compacted waste generated on a particular day varies significantly from the size of a *cell*. A detailed description of the algorithm for recursive spatial decomposition and area-covering path planning is provided in Kunigahalli et al. [6].

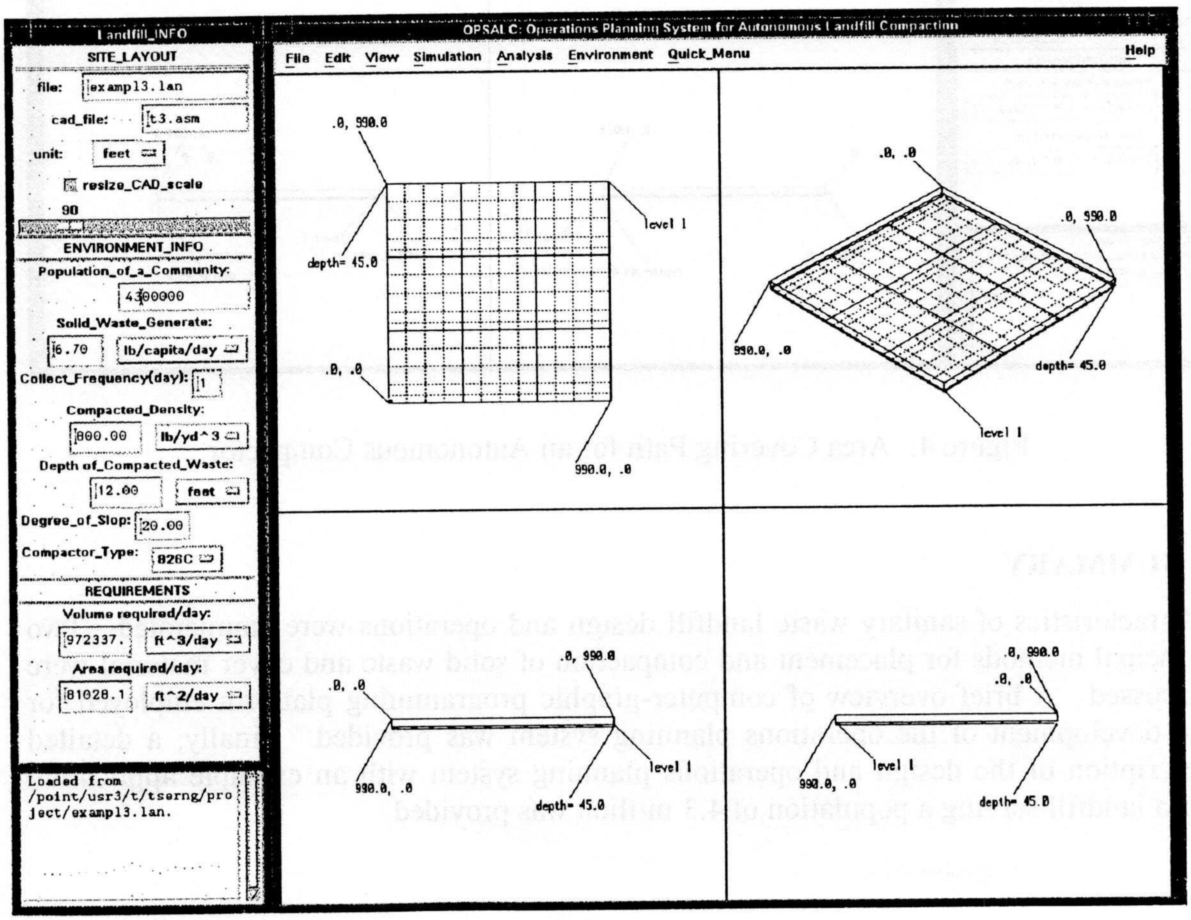

Figure 3: Partitioning of an Example Landfill Site

Figure 4 shows a simulation of an area-covering path for an autonomous compactor in a portion of a *cell* that corresponds to two monominoes. However, intermittent operation of the compactor at various different time on a single day is possible using this approach.

Figure 5 shows an enlarged plan-view of the complete landfill. Bottom-right cell of layer 1 is already filled and compacted. The compaction process has just begun in two bottom-right monominoes of the adjacent cell.

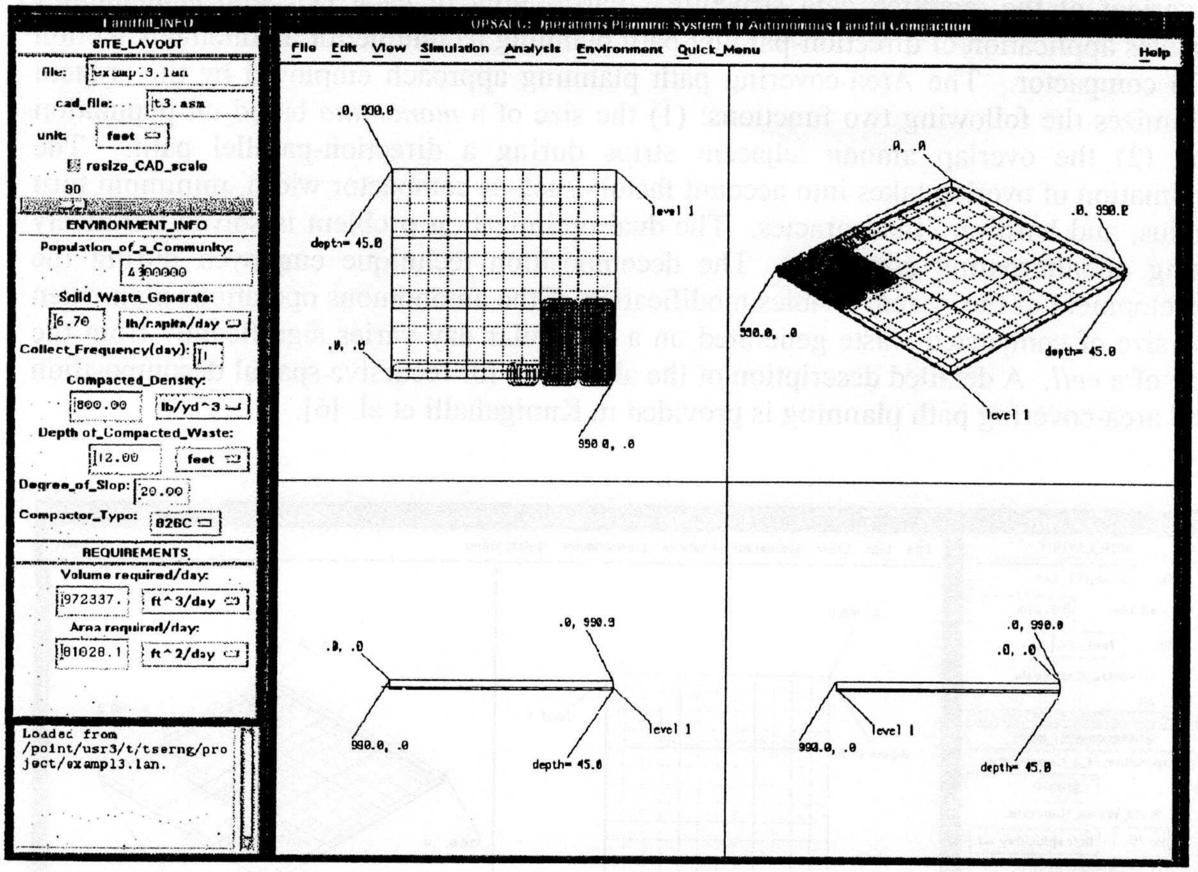

Figure 4: Area Covering Path for an Autonomous Compactor

5. SUMMARY

Characteristics of sanitary waste landfill design and operations were enumerated. Two principal methods for placement and compaction of solid waste and cover material were discussed. A brief overview of computer-graphic programming platform employed for the development of the operations planning system was provided. Finally, a detailed description of the design and operations planning system with an example application for a landfill serving a population of 4.3 million was provided.

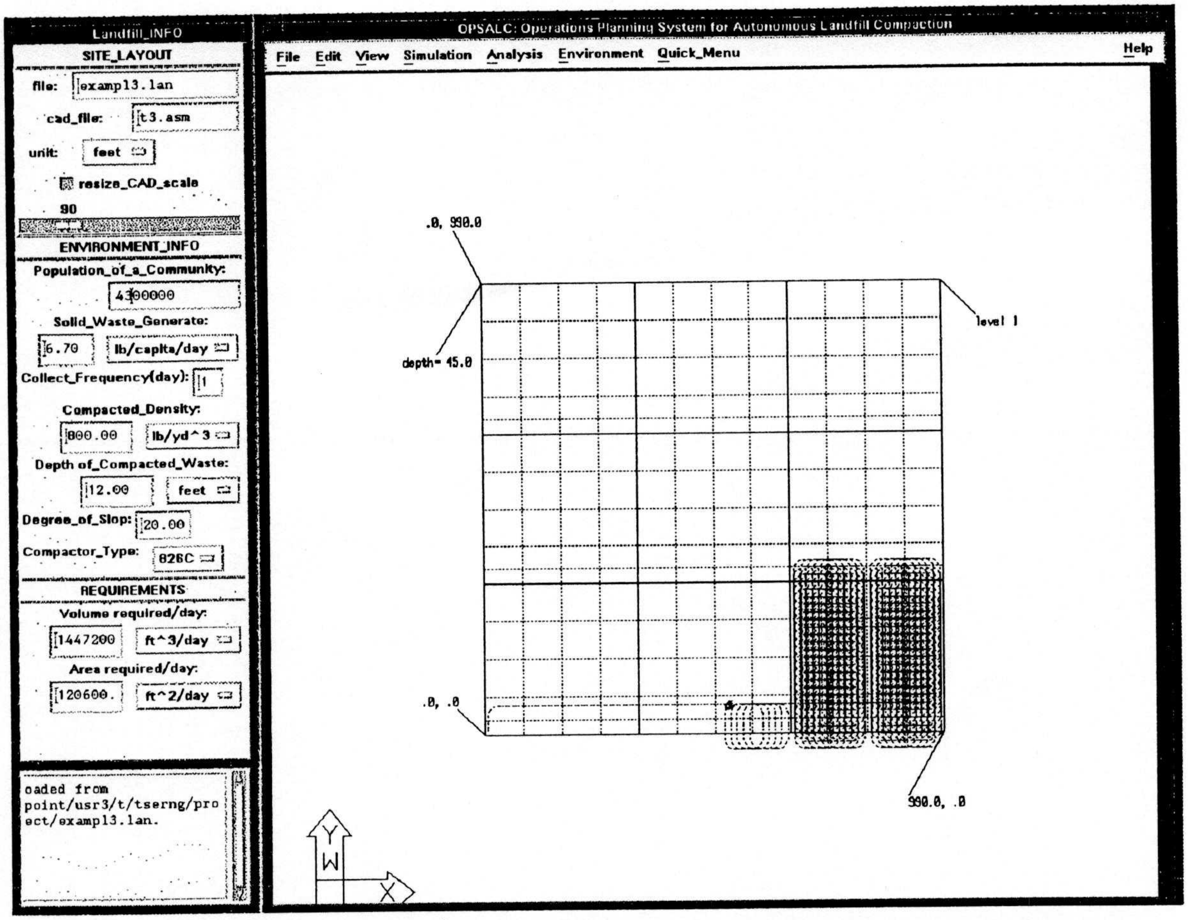

Figure 5: Enlarged Plan View of a Partially-Filled Landfill

6. REFERENCES

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