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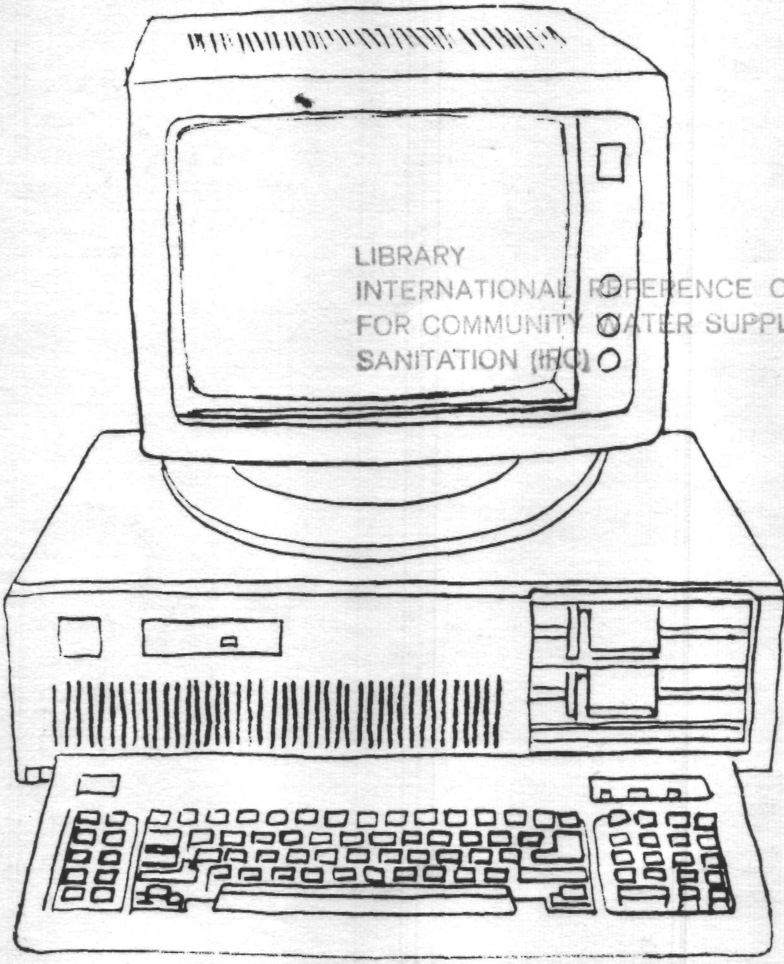
Microcomputer Software in Municipal Solid Waste Management: A Review of Programs and Issues for Developing Countries

by Gary L. Light



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MICROCOMPUTER SOFTWARE IN MUNICIPAL SOLID WASTE MANAGEMENT

A Review of Programs and Issues for Developing Countries

UNDP-World Bank Water and Sanitation Program

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IN MUNICIPAL SOLID WASTE MANAGEMENT

A Review of Programs and Issues for Developing Countries

by Gary Light

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ABSTRACT

This discussion paper reports on the initial findings of a survey of existing microcomputer software programs for the monitoring of municipal solid waste management (MSWM) and examines the extent to which they or similar programs could be applied in developing countries.

The paper examines programs designed for stategic planning, equipment maintenance management, billing and accounting, and general applications. It briefly describes the programs' features and their relative advantages and shortcomings, particularly as these relate to the developing country context. Also discussed are such issues as cost, user expertise, the availability and reliability of input data, and the need to tailor programs to take local waste management practices into consideration.

The paper concludes that, although none perfectly matches the need at present, certain microcomputer software packages could support the MSWM planning efforts in developing countries by providing a useful training tool for local waste managers, demonstrating the need for reliable data collection, and indicating the most important data to be collected.

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I. INTRODUCTION

Solid Waste Management in Developing Countries

Solid waste management problems continue to plague many urban areas of developing countries, where cities spend 20 to 40 percent of their revenues on refuse collection and disposal, yet fail to collect 30 to 50 percent of their solid wastes.[1] Without adequate collection and reuse or disposal, solid wastes obstruct drainage, promote disease vectors, and are aesthetically offensive. These problems are particularly acute in the sprawling, impoverished areas surrounding many major cities.

Numerous obstacles impede the provision of adequate solid waste management services, not the least of which is that solid waste services are often a low political priority. Weak institutional arrangements result from the dispersal of planning and management among multiple agencies. Capital resource shortages also limit service provision, and available equipment often is used inefficiently or is inappropriate for the conditions in which it is operated. It is widely held that improved service efficiency and increased cost recovery are necessary to allow expansion of service in poorer areas. As urban areas grow, so too do the volumes of wastes generated and the complexities of collecting, transporting, and disposing of them. Given the current growth rates of cities in the developing world, the problems of waste management planning are likely to worsen unless major efforts are undertaken to improve the planning process.

Microcomputers in Municipal Solid Waste Management (MSWM)

Low-cost microcomputers are increasingly relied upon in industrialized countries to support municipal solid waste management planning and operations. A recent survey of United States local, county, state, and regional public waste management officials indicated that nearly half make use of a PC AT class microcomputer,[2] and fifty-three out of sixty-four respondents believed that a microcomputer program for estimating solid waste disposal costs would be useful if it were easy to use and cost less than $1,000.[3] In addition, many public and private solid waste collection and disposal operations rely on microcomputers to track operating records and provide management information.

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1. Cointreau, 1982.

2. Personal computers that conform to original International Business Machines (IBM) standards are often referenced by the original IBM model--PC, XT, or AT--to indicate the type of processor employed. An AT class microcomputer typically contains an 80286 processor and hard disk and is more powerful than the PC or XT class.

3. Shaub, 1987.

Microcomputer use is growing in developing countries, where public officials have increasing access to computing power for general purpose word processing and for spreadsheet and database programs. This availability has given rise to customized application programs for investment planning and for the operation and administration of waste management programs. Special purpose programs often serve generalizable functions, but because they conform to no established standards and lack operability features such as control menus and error protection, they are difficult to use for individuals or organizations who did not participate in their development, or who are not computer experts. As the number of users of a program increases, it becomes more economical to add features that simplify its operation.

Development agencies, which play a major role in spreading microcomputer technology in developing countries, are uniquely able to distribute special purpose application programs to a large number of users. This ability is demonstrated by the fact that many World Bank urban projects provide for microcomputer equipment, and agency staff and consultants commonly use microcomputers to prepare and appraise these projects. In some areas, efforts have been made to develop and distribute special purpose application programs. For example, the United Nations Development Programme and the World Bank distribute a set of microcomputer programs for planning and designing water supply and waste disposal systems through the International Drinking Water Supply and Sanitation Decade.[4] Also, the Water and Sanitation Division of the World Bank's Infrastructure and Urban Development Department has developed a spreadsheet model for evaluating costs, capacity requirements, and cash flows for alternative waste composting strategies, and the Urban Division has developed a spreadsheet model for comparing costs of alternative vehicle and crew arrangements for garbage collection systems.

To a far greater extent, concern for the environment and recognition of the rapid depletion of landfill capacity is indirectly driving many public and private organizations in industrialized countries to develop microcomputer programs to support increasingly complex MSWM decision making. Recognizing the potential utility of microcomputers in MSWM, and the economic advantages of central development and widespread distribution, these producers hope to replace more arcane custom programs and to support users with limited computer expertise. This report discusses how these programs address numerous aspects of solid waste management and the extent to which they or similar programs could be applied in developing countries.

The MSWM Software Survey

The Water and Sanitation Division of the World Bank's Infrastructure and Urban Development Department, through the UNDP-World Bank Drinking Water and Sanitation Decade Program Integrated Resource Recovery/Waste Management Project (INT/87/035), reviewed waste management related software for personal computers. Our objectives were to

4. The Technical Advisory Group (TAG), United Nations Development Programme Interregional Project INT/81/047, Microcomputer Programs for Improved Planning and Design of Water Supply and Waste Disposal Systems, Executing Agency: World Bank. Washington, D.C.

identify the types of programs currently being used in developed countries, determine their functions and potential benefits, and consider the issues that would affect their application in developing countries. This report presents our initial findings.

Electronic bibliographic searches were used to identify published material pertaining to microcomputer application in MSWM. Application software catalogs were also explored, as were recent issues of MSWM trade and professional publications. In several cases, MSWM-related government agencies, professional organizations, and international development agencies were contacted directly.

Only products specifically developed or known to be used for MSWM related applications were considered. In addition, software had to operate on a microcomputer and be distributed outside of the organization that developed it. General application programs, such as those for spreadsheets and databases, were not explicitly reviewed, but their potential usefulness is discussed. Hazardous and industrial waste management programs, including specialized regulatory compliance software, are outside the scope of this investigation.

Resource and time constraints precluded an exhaustive search, but conversations with individuals in the field helped to identify a substantial sample of products from commercial and public sources in North America, and to a lesser extent in Europe. More than seventy organizations were contacted. Nearly one hundred programs were identified, and information was collected on twenty-two products that fall within the scope of consideration.

This report is based on the few programs about which information was received. Information came from product manuals, descriptive literature, and/or demonstration programs. Consequently, this report will not present a comparative evaluation of individual products, but will instead discuss categories of programs and provide examples of different approaches. Each program category will be discussed in turn, followed by more general conclusions pertaining to the use of MSWM-related microcomputer software in developing countries.

Summary of Findings

To organize the discussion, software products have been broadly categorized as either tools for planning or for attaining operating efficiency. Planning programs are used to analyze performance and costs of alternative waste management strategies. They may address one or more of the following aspects of MSWM: waste generation, separation of waste components at their source, storage and collection of wastes, transport of waste from collection areas to intermediate processing systems, transport of wastes to landfills, and waste disposal at landfills. Intermediate processing systems include transfer stations, composting facilities, incineration plants, and materials recycling centers.

Planning programs can be further divided into strategic and tactical planning models, depending on the time frame they address. Strategic planning programs characterize long-term (up to twenty-year) service performance and cost parameters to assist in selecting appropriate investments. For example, the annualized capital, operating, and maintenance costs for a proposed incinerator may be computed. Tactical planning programs focus on shorter-term (up to five-year) resource utilization planning, such as collection route planning and storage container replacement. More comprehensive programs produce information that could support decisions for a wide range of time horizons. Programs that evaluate an explicitly defined strategy (evaluation programs) were identified, as were programs that include routines for optimizing less rigidly defined systems (optimizing programs). Table 1.1 highlights the planning programs reviewed.

Operational efficiency programs, on the other hand, provide daily, weekly, or monthly record-keeping and administrative support to an existing waste management facility or program. Such tools include billing and accounting programs, maintenance management programs, and data collection programs. Table 1.2 highlights examples of identified operational efficiency programs.

The distinctions between planning and operational efficiency programs, and between types of programs within these categories, are far from absolute. Management information provided by accounting programs would be useful in planning, and collection route planning programs could support daily scheduling. These generalizations are intended merely to organize the following discussion.

Planning programs account for the bulk of the review for three reasons. First, there are fewer of them and they are more functionally complex than operational efficiency programs. Second, they are closely related to investment decisions of the type required by World Bank projects. Third, the information received regarding commercially distributed operational efficiency programs was generally promotional and did not support the same level of review detail as the information pertaining to planning programs.

Both of the data collection programs listed in Table 2.1 are packaged with special purpose hardware. The AUTOSCALE program automates record keeping of scale readings, and the DUMP system includes specialized on-board hardware for collection vehicles. These products may be quite useful, but because of their special hardware requirements they will not be discussed further.

TABLE 1.1

Planning Program Summary

Name and Distributor	Description	Price	E/O[5]
ECO Northwest Model Oregon Department of Environmental Quality Portland, Oregon	Models benefits and costs of sanitary landfilling	$25	E
SW Financial Model California Waste Management Board Sacramento, California	Models integrated materials recycling, incineration, and sanitary landfilling system[6]	$100	E
Harbinger Environmental Safety Centre Harwell Laboratory Oxfordshire, United Kingdom	Models generation, transport and disposal of wastes at multiple, generically defined sites	$15,000[7]	O
IWMS The Conservancy Incorporated Naples, Florida	Models integrated materials recycling, composting, incineration, landfilling, and landfill mining system	$395	E
REPEP Illinois Department of Energy and Natural Resources Springfield, Illinois	Models collection and processing for materials recycling programs	FREE	E

5. "E" indicates evaluation or nonoptimizing programs and "O" indicates optimizing programs.

6. Materials recycling refers to separation and reuse of materials such as paper, glass, and aluminum.

7. Price is approximate, based on application in cities of the United Kingdom and includes training services.

TABLE 1.1 (cont.)

Name and Distributor	Description	Price	E/O
ROMA Beture Paris, France	Models refuse collection route systems	Unknown[8]	O
RRPlan[9] United States National Bureau of Standards Office of Recycled Materials Washington, D.C.	Models integrated system of multiple materials recycling, incineration, and landfilling facilities	$100	O
Second Opinion Economics Plus Incorporated Cambridge, Massachusetts	Models integrated system of materials recycling, incineration, and landfilling	$950	E
WastePlan Tellus Institute (formerly Energy Systems Research Group) Boston, Massachusetts	Models integrated collection, materials recycling, composting incineration and landfill system	[10]	E
Cocompost UNDP/World Bank Decade Program Washington, D.C.	Models alternative capacity composting plants	FREE	E

8. The information obtained on ROMA is from an article published in 1979. No recent information was found.

9. RRPlan was originally developed for mainframe computers. Development of a microcomputer version has begun but appears to be stalled by budgetary constraints.

10. Price of statewide license and technical support is $20,000 for first year and $10,000 for each succeeding year. This price allows a state to distribute the model to an unlimited number of municipalities within the state.

TABLE 1.2

Summary of Operational Efficiency Programs

Maintenance Management	Description	Price
Fleet Command System Mainstem Incorporated Sewaren, New Jersey	Tracks vehicle operation records and includes employee productivity and inventory reporting	$14,500[11] +
Wheels CISCO Incorporated Severna Park, Maryland	Tracks vehicle operation records and includes inventory and usage reporting	$2,500 +
Preventive Maintenance & Inventory Management Josalli Incorporated Enka, North Carolina	Tracks equipment repairs and inventory and prepares maintenance schedules	$1,500[12]
Vision Systems Caterpillar Incorporated Peoria, Illinois	A variety of programs for selecting and maintaining vehicles and equipment	Unknown
VEHICLEMANAGER Compware Whittier, California	Tracks vehicle inventory, maintenance, and usage and includes cost per vehicle reporting	Unknown
Accounting and Billing		
Delta Refuse System Delta Equipment Systems Carmel, Indiana	Maintains customer accounts and inventory records and includes route productivity reporting	$5,645[13] +

11. Price includes hardware.

12. Preventive maintenance and parts inventory modules may be purchased separately.

13. Price includes hardware.

TABLE 1.2 (cont.)

Maintenance Management	Description	Price
swdMANAGER National Software Eau Claire, Wisconsin	Maintains customer accounts and equipment inventories	$8,928[14] +
Trash Hauler's System Jayhawk Software Lawrence, Kansas	Supports billing	$495 +
Waste Management System SANDATA Port Washington, New York	Maintains customer accounts and supports billing	Unknown
Waste Manager SCS Incorporated Portland, Oregon	Supports all accounting functions and prepares route sheets	Unknown
RAMS III Desert Micro Scottsdale, Arizona	Maintains customer accounts, supports billing, and prepares route sheets	Unknown
Data Collection		
DUMP Developmental Enterprises Corp. Clinton, Massachusetts	On-board data collection system for waste collection vehicles	Unknown
AUTOSCALE Automation Services Inc. Lexington, Kentucky	Automated weigh-scale record management system	Unknown

14. Price includes hardware.

II. STRATEGIC PLANNING PROGRAMS

Purpose and Expected Benefits

Strategic planning programs provide a generalized framework for analyzing and comparing costs and performance of alternative waste management strategies. Municipal waste managers and planners who use these models expect to benefit from a computer's ability to perform a multitude of predefined calculations quickly and repeatedly. By simulating MSWM strategies before committing resources to a specific set of facilities or programs, planners and managers hope to identify major cost and performance determinants and the project's sensitivity to these determinants. These efforts in turn can further focus data collection activities. Ultimate benefits take the form of avoided unnecessary costs and maximum service provision from the most appropriate mix of labor, equipment, and financing system.

The different strategic planning models share the objective of estimating performance and costs of MSWM, but they vary in scope, level of detail, methodology, and degree of decision support. Some models characterize an individual collection or disposal process or program, such as a landfill, recycling program, or collection system. Integrated strategic planning programs consider a variety of waste handling processes and concentrate on the interdependencies of waste management system components. Because the interdependence of waste collection, transport, recycling, and disposal systems is so important and complex, integrated planning models provide the greatest potential for assisting decision makers. For example, an integrated planning model could allow planners to consider the impact of materials recycling on the energy production of incineration plants or the lifetime of landfills.

WastePlan and Harbinger are two of the most comprehensive and widely applied integrated planning models. Because they use quite different approaches, they provide most of the examples in the ensuing discussion. WastePlan explicitly considers multiple simultaneous recycling, composting, and resource recovery programs with separate sanitary and ash landfills. Harbinger, by accepting generalized facility cost and performance data entry for up to twenty user-defined facilities, imposes few restrictions on the type of facility considered.

Strategic planning programs explicitly address different types of collection, transport, recycling, and disposal options. In general, comprehensive model detail is offered at the expense of strategy flexibility. The next five subsections (Characterizing the Waste Stream through Net Cost Estimation) in turn discuss different approaches to determining the characteristics of waste streams, defining waste collection and transport systems, allocating wastes to handling processes, specifying program and facility attributes, and estimating net costs.

Characterizing the Waste Stream

Strategic planning programs differ in their method of quantifying and characterizing waste streams. The simpler models, primarily those of individual disposal methods, accept totally aggregated waste quantities for a unit time period (for example, the total number of tons generated or processed per year). The most sophisticated models use demographic data, unit waste generation rates for different generating sectors, and waste composition to estimate detailed waste stream flows.

Waste streams are in some cases separated by geographic area and generating sector so that collection, transport, and disposal methods can be treated independently. Residential and commercial wastes are almost always differentiated. WastePlan distinguishes between single family and multifamily household wastes in urban, rural, and suburban areas, and it identifies wastes from individual commercial activities. Harbinger allows its users to specify four basic wastes from each generating region, each of which can be further divided into constituent components.

Models such as WastePlan, REPEP, SW Financial Model, and RRPlan, explicitly address energy or materials recovery and require that waste material composition and properties such as density, heat content, moisture content, ash content, and chemical composition be specified.

The method of projecting waste generation across the planning period also varies between models. One approach, employed by Harbinger and IWMS, requires users to specify demographic and waste generation data for a base year, along with anticipated annual growth rates for future years. With this approach, data from one phase of a planning period can be carried over into another in which a new handling process may be started. WastePlan accepts beginning- and end-year estimates, and it interpolates for interim years. Some models do not explicitly account for growth, and they require consecutive incremental runs to effectively consider long-range planning.

Waste Collection and Transport

Models differ significantly in their treatment of waste collection. Harbinger does not consider waste collection costs at all, while ROMA is dedicated solely to optimizing refuse collection routes. WastePlan uses waste stream data, container and vehicle capacities, crew specifications, and route timing parameters to determine the number of storage containers, collection vehicles, and workers required to meet service demands. Unit labor and equipment costs are used to calculate overall costs of collection. Separate systems (for example, routes, schedules, containers, vehicles, and crew) may be defined for collecting and transporting recyclable, compostable, or burnable wastes to the appropriate facility.

Most models distinguish between transportation from collection areas to processing facilities and transportation within collection routes. Models such as Harbinger use detailed transportation network specifications, waste flows, and vehicle capacity constraints to define minimum-time truck routes between generation, treatment, and disposal areas. WastePlan estimates transportation costs from the total number of route miles in the planning area, the specified fraction covered by each collection program, and the distance from each collection area to its tipping area.

Most integrated models allow users to analyze potential cost savings from using transfer stations. WastePlan allows explicit specification of a single transfer facility, while Harbinger's generalized approach allows specification of a secondary waste stream from any intermediate facility that could be a transfer station.

Specification of Waste Handling Processes

For strategic planning models to be able to calculate costs and operating requirements, wastes must be allocated to one of the primary handling processes (such as recycling program, incinerator, or landfill). One approach to waste allocation takes into account the percentage of each constituent of a waste stream to be diverted to each primary handling process. In this case, the model calculates required process capacities, or if individual facility capacities are specified, the number of required facilities.

A second approach relies on individual facility capacity inputs to estimate the fraction of the waste stream that each process can handle. Harbinger incorporates this approach and provides optimization features to determine the minimum cost distribution of wastes among facilities. If the specified facilities do not have sufficient combined capacity, Harbinger indicates that the chosen strategy is infeasible.

Secondary waste streams from primary processes (such as ash from incinerators) must also be allocated to a disposal facility (landfill). In most cases, secondary streams are specified as a volume or mass fraction of the input stream. For example, compaction rates may be used to quantify secondary streams from a transfer station.

Facility and Program Specifications

Some models use performance factors to relate routed waste quantities to specific physical and operational facility characteristics that are the basis of cost estimates. Such intermediate outputs include landfill or treatment plant size, equipment specifications, or human resource requirements. Facility-oriented models, such as Harbinger, allow users to specify capacity ranges for multiple individual facilities for each handling process. Waste-oriented models, such as WastePlan, assume a single facility (or in some cases, such as resource recovery, as many as four facilities) of each type, and use waste stream assignments to estimate capacity requirements. To circumvent the limitations of assuming a finite number of facilities for the planning area, WastePlan allows the importing and exporting of wastes to and from the planning region. With this feature, one could model multiple facilities by defining each planning area as the area served by an individual facility, and by defining the exchange of wastes between the separate areas.

Depending on the model, requirements for land, labor, and equipment may be specified on a unit capacity or service level basis or as subtotals for a handling process component. If unit requirement factors alone are used, the program outputs include the number of acres, workers, or equipment items required to meet the demands of the strategy without considering economies of scale. When physical and human resource requirements are entered as independent fixed-factor subtotals for a process or facility, the model accounts for economies of scale in its calculation of factor requirements per unit throughput.

Strategic planning models vary in their ability to consider another important dynamic: varying start-up schedules for different facilities. Harbinger considers a multistage planning period, allowing wastes from one stage to carry into the next period in which a new facility may be brought on line. Most of the other models make some allowance for the remaining-life-existing facilities at the beginning of the planning period, but they require that any new program or facility begin operation in the base year of the plan.

Net Cost Estimation

Cost estimation is the central purpose of strategic planning models. Most models concentrate on costs or revenues incurred or received by a municipality in charge of MSWM. Harbinger allows designation of costs to different sectors or agencies, but most other models would require separate analysis of costs for each organization that incurs a cost.

To allow comparison of costs between alternative strategies, strategic planning programs discount costs to either a net present value or an annualized value over the planning period. Further commonality is often obtained by figuring costs on a per-ton-of-waste basis. Estimation of capital, operating, and maintenance costs requires that relevant cost factors be ascertained and entered into the model.

For each facility or program, capital cost factors for such items as land, buildings, and equipment must be entered. Some programs require users to aggregate capital costs for each year without the support of the model. Others, such as WastePlan, provide template worksheets for entering capacity, unit cost, and lifetime parameters for each major capital cost component of each facility type. These major capital cost components include land acquisition, site preparation, building construction, and major processing equipment items. Land requirements may be either fixed or a function of facility capacity, depending on the model. Most models base capital facility costs on unit throughput capacity, and capital equipment costs on unit price and required quantity.

As with capital costs, some models accept only aggregated operation and maintenance cost inputs, while others accept detailed components such as labor, utilities, fuel, insurance, and repairs. The more sophisticated models allow both fixed and throughput-dependent operating costs. Utilities and fuel are typically specified per ton of processed waste, while insurance and repairs are specified as a percentage of building or equipment costs.

For resource recovery systems such as materials recycling, composting, and waste-to-energy facilities, unit revenue parameters must also be entered. Models of specific recovery systems facilitate entry of specific revenue factors, such as the price per ton of recycled newspaper. Harbinger employs a generalized approach to revenue generation by allowing its users to enter a unit of conversion from processed throughput to saleable product (such as KW hours/ton), and the corresponding unit price of the saleable product (such as $/Kw hour).

Financing methods are not a central consideration of most of the planning models reviewed, though Second Opinion considers a number of financing options. Most programs consider revenues from collection and transport fees, where fees usually are specified on a unit weight or unit weight times distance.

Program Outputs

Strategic planning programs report overall and component cost and performance factors. Often, reports may be either viewed on the screen or printed. The quantity of waste in each specified waste stream sector is usually reported, along with important operating requirements such as facility capacities and crew sizes. Annual and total costs are typically reported along with any revenues from sale of materials or energy. Costs are usually broken down by process and summarized for the entire strategy under consideration. Harbinger allows side-by-side cost and performance comparison of two alternative strategies.

General Planning Programs: Features and Considerations

The type and degree of interaction between planners and computer programs are important determinants of program utility. How a planner enters data and controls program operation is different for each program. Highly interactive programs sequentially prompt users for yes/no responses to control option questions. Less interactive programs provide menus of each available control option at any point in the program. Menu operation simplifies navigation through the program, but it requires users to know which steps are required to complete a desired operation.

Data entry interaction is an even more important operational consideration. More interactive models step users through the process of entering each individual data item. This interactive approach often makes it impossible to interrupt and resume data entry without losing the data already entered. A preferred batch entry approach provides logically organized and labeled input screens that can be entered, stored, and modified freely. The batch approach simplifies data entry and sensitivity analysis after a base case set of inputs has been defined and saved. The batch input approach also facilitates generation and maintenance of a database of model inputs. Figure 2.1 depicts an example of the WastePlan's batch data input screen for entering collection system parameters for a commingled materials recycling program. Wages and equipment costs and capacities are entered via other input screens.

Fig. 2.1 Sample WastePlan Input Screen for Collection System Parameters

Single-Family Commingled Collection Data

Truck type:	Closed Body Recycle					
Workers per crew:	1.0					
Stops per hour:	Urban	50.0	Suburban	90.0	Rural	60.0
Households per stop:	Urban	2.0	Suburban	1.3	Rural	1.0
% of route miles:	Urban	40.0	Suburban	50.0	Rural	10.0
Miles per hour to, from dropoff:	20.0					
Average mileage to dropoff:	5.0					
Collection days per week:	5.0					
Collection weeks per year:	52.0					
Pickups per week:	1.0					
Program administration cost:	0.80 ($/household)					
Container type:	Blue box					
Annual replacement rate:	5.00%					

Note: The data in this example refers to the state of New York.

Another fundamental distinction among various strategic planning programs is the type and degree of decision support they provide. Most programs, including WastePlan and IWMS, are simply evaluation programs. These perform the calculations necessary to estimate costs and performance for the specified scenario, but they do not explicitly indicate how to improve that scenario.

Optimizing programs such as Harbinger and RRPlan use mathematical programming to search systematically among a range of feasible scenarios for the optimum least-cost solution. For example, optimization programs may recommend specific facility sites from an array of candidates, or the amount of waste that should be transported from each waste generating area to each disposal facility.

Optimization techniques reduce the guesswork of improving system performance and greatly increase the number of feasible strategies that can be considered, but they may present technical and operational difficulties. Linear optimization methods require simplifying assumptions such as linearity of aggregated costs over an entire range of feasible operating throughput. Moreover, the mathematical basis for optimization programs is much more complex than that of evaluation models, making it more difficult to operate and interpret these models. As a rule, optimization models also require greater computer power or take longer to run than evaluation models.

Different programs represent different trade-offs between detail support and model flexibility. These trade-offs affect many areas of program data entry, but those for capital costs provide an example. Models such as IWMS require completely aggregated annual capital cost inputs. Thus, the user could consider any capital item, but he would receive no support from the model in determining what costs can be expected.

A higher level of detail provides an empty list into which the user enters equipment identification and cost. Any item can be specified, and the computer takes care of the summation, but there is once again little or no guidance in deciding what items to consider.

The highest level of detail, as provided by WastePlan, provides a comprehensive list of possible equipment items for a specific type of facility. In this case, the user enters figures only for the applicable items, while other items are ignored. An advantage is that the model includes the expertise of the model developer, and it guides a user toward important considerations that otherwise might have been ignored. Another advantage of highly detailed inputs is that default values, if known in advance, may be provided in the model's standard form. On the other hand, this approach requires more extensive development, and it risks ignorance of a specific application's unique circumstances. Detailed models often mitigate this risk by allowing additional unspecified items in each input category, or by allowing, but not requiring, detailed data inputs.

Applicability to Developing Countries

Meaningful application of planning programs depends heavily on reliable input data, which typically are lacking in developing countries. Default data commonly provided with planning programs are taken from national or regional averages in developed countries and in most cases would not apply to developing countries. Table 2.3 demonstrates the dependence of waste generation rates and waste characteristics on average national income. The collection of reliable local data is therefore one of the most critical steps in planning MSWM strategies in developing countries.

TABLE 2.3

Municipal Refuse Generation Rates and Composition for Low, Middle, and Upper Income Countries[15]

	Low-Income Countries[16]	Middle-Income Countries[17]	Industrialized Countries
Waste generation (kg/cap/day)	0.4 - 0.6	0.5 - 0.9	0.7 - 1.8
Waste densities (wet weight basis kg/cubic meter)	250 - 500	170 - 330	100 - 170
Moisture content (percent water weight at generation)	20 - 80	40 - 60	20 - 30
Composition (Weight percent)			
Paper	1 - 10	15 - 40	15 - 40
Glass, ceramics	1 - 10	1 - 10	4 - 10
Metals	1 - 5	1 - 5	3 - 13
Plastics	1 - 5	2 - 6	2 - 10
Leather, rubber	1 - 5	-	-
Wood, bones, straw	1 - 5	-	-
Textiles	1 - 5	2 - 10	2 - 10
Vegetable/putrescibles	40 - 85	20 - 65	20 - 50
Miscellaneous inerts	1 - 40	1 - 30	1 - 20

15. Cointreau, 1982, p. iv.

16. Countries having a per capita income of less than US$360 in 1978.

17. Countries having a per capita income between US$360 and US$3,500 in 1978.

Intuitive structures and menus make operation of most planning programs appear relatively easy, though basic familiarity with computers would be necessary. A far greater problem is likely to arise from the difficulty of interpreting what the computer puts out. A recent study of microcomputer application to planning and finance in Kenya and Indonesia concluded that the inability to interpret and analyze program outputs was among the greatest barriers to microcomputer adoption.[18] Since planning models are likely to produce new types of information, training in the use of outputs is particularly important. In the worst cases, the very idea of planning may have to be taught as part of implementing a computer model.

Proper strategic planning requires careful consideration of existing conditions. Planning models in some cases make implicit technology assumptions that may be inappropriate or only remotely feasible in developing countries because of technology or cost constraints. Incineration with net energy recovery is an example of a technology that is widely considered in developed country models but is not likely to be feasible in developing countries because of the high organic and moisture contents of their domestic waste and large capital requirements for energy recovery facilities. So long as the program considers all feasible alternatives, no functionality is lost, and the model should in fact demonstrate that a technology is inappropriate. At worst, extra features might render model operation and interpretation more cumbersome than necessary.

A more difficult problem is presented by the opposite case, when models ignore waste management practices that are common to developing countries. One such practice that none of the models explicitly considered is informal recycling in the form of scavenging. Scavenging in residential areas could be counted as a curbside recycling program with no internalized labor or equipment costs, though quantitative data would be difficult to obtain. Landfill scavenging could be treated similarly, but doing so may be difficult if the chosen program considers only a single recycling facility. While such adaptations of model components may provide a rough characterization of reality, it is unlikely that they will adequately account for scavenging's effects on operation of the landfill.

The extent of waste collection is another area where developed country models do not adequately represent developing country conditions. Some programs assume that all generated wastes are collected--an assumption that would be inappropriate where localized open dumping is commonly practiced. Partial collection probably could be accounted for by adjusting generation rates, but this approach would not be ideal.

A third area of difference pertains to storage and collection. In many poor peri-urban areas of developing countries, the concentration of residences and the lack of paved roads limit local access and prevent the use of motor vehicles for primary collection. Furthermore, in tropical climates, solid wastes may require daily collection. Under these conditions, a variety of storage containers may be used, and collection may involve human- or animal-powered vehicles. Wastes collected in this manner may then be transferred through community storage sites to collection trucks that service the region's wealthier areas. From collection trucks, wastes may be transferred to larger hauling trucks at more conventional transfer stations.

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18. Brodman, 1986.

None of the models reviewed consider simultaneous use of more than two types of collection vehicles or two stages of transport. WastePlan comes close to meeting the need by allowing separate specification of single and multifamily storage and collection systems for urban, suburban, and rural areas.

The differentiation of local costs from foreign exchange is another feature that might be important to developing country planning but is not part of any model reviewed. Sandra Cointreau points out that the least-cost MSWM strategy may not be the best strategy if slightly higher costs produce more employment in the local area and reduce the demand for foreign exchange.[19] Cost modeling in this context should use shadow pricing.

Institutional arrangements affect both the incentives to use strategic planning models and the appropriateness of their technical assumptions. Where institutions are weakest, MSWM responsibilities dispersed, and formal planning mechanisms nonexistent, it is unlikely that planning models could be used effectively within a municipality. If a planning agency exists or is being formed, however, a planning model could serve as a training mechanism as well as a decision support tool. In addition, planning programs have been and will continue to be useful to private consultants. The ability of microcomputer introduction to serve as a catalyst for promoting planning within government agencies has been reported in ministries of several countries in the Sahel.[20]

Institutional arrangements also affect cost allocation of strategy components. If, for example, a private collection contractor is employed, the detailed collection equipment costs may not be relevant to the municipality. Community-offered services in kind should also be accounted for, even though they may not represent financial costs to the municipality. Harbinger distinguishes between costs to public and private sectors, making it easier to address issues of cost distribution.

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19. Cointreau, 1982.

20. Bertrand, 1987.

III. EQUIPMENT MAINTENANCE MANAGEMENT PROGRAMS

Purpose and Expected Benefits

One type of operational efficiency tool is the maintenance management program, which organizes equipment and facility records and automates procedures for scheduling preventive maintenance and repairs. Some also produce cost and productivity statistics for equipment or vehicles.

Any individual or agency that must track and plan equipment or facility maintenance could potentially benefit from computerizing its management. The usefulness of such programs is indicated by their widespread use. Several producers of maintenance programs boast more than one hundred users. The users expect to reduce equipment down-time, improve the accuracy of management data, and sharpen administrative efficiency.

Maintenance programs consist essentially of integrated databases containing equipment specifications, spare parts inventories, preventive maintenance procedures, parts and labor specifications, and equipment service histories. Calendar and maintenance interval information is used to project maintenance service schedules for each piece of equipment. Programs are also provided for printing service schedules and work requests and for logging completed service. Service histories are typically maintained for each piece of equipment.

Program Variations

Most programs serve the same basic purpose, but some important functional details vary among them. Some have more capacity than others, but even the least sophisticated can handle at least one hundred spare parts or equipment items. Some allow scheduling intervals to be specified by elapsed time, hours run, or miles run, while others consider elapsed time alone. Programs that maintain spare parts records typically provide automated purchase reminders when inventories fall below a predefined minimum threshold based on user-specified lead time required to obtain the part. The most sophisticated programs also track equipment depreciation and fuel usage and provide data analysis programs to produce management reports. Equipment service arrangement assumptions (such as in-house vs. contract) vary and are an important functional distinction. Programs also vary in report flexibility, input and output data formats, degree of customizing available, and the length of history maintained.

Issues

Equipment maintenance management is a serious problem in developing countries. Cointreau estimates that there is typically one supervisor for ten to thirty vehicles in developing countries, as against approximately one for five to seven in developed countries. This ratio underscores the need for support in organizing and tracking fleet management. In developing countries, waste collection vehicles are inoperative between 20 percent and 50 percent of the time, compared with 10 percent to 20 percent in developed countries.[21] The lack of preventive maintenance is widely recognized as a major contributor to high vehicle down-times.

Maintenance management programs show great potential for assisting MSW managers in developing countries, but successful application depends a great deal on existing conditions. Regardless of the level of technology used, preventive maintenance is an important aspect of reducing costs and regularizing service. Menus make maintenance management programs easy to operate, and the lack of sophisticated analysis features make them easy to understand, especially if similar information is already filed and maintained by hand. And the programs do not make inappropriate technology assumptions, because equipment items are generally user defined. These programs could improve operations in cases where maintenance problems are attributed to management shortcomings, but they would do little to solve problems attributable to financial resource shortages.

Maintenance management programs require frequent and detailed entry of transaction information. To be useful, these programs require significant commitment from the user to update data and to adhere to maintenance schedules. Collecting the data to set up the program is a formidable task if records have not been maintained. The information audit itself, however, may result in institutional improvements, as has been reported during computerization of equipment and personnel records in ministries in several Sahelian countries.[22]

Because maintenance management programs can be applied across a broad range of equipment types, multiple agencies within a local government could use them. This flexibility would be especially useful if a centralized agency were responsible for maintaining all municipal vehicles and facilities. The programs could be applied equally well in government and business organizations, assuming that incentives to adopt the system are present in either case.

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21. Cointreau, 1982.

22. Bertrand, 1987.

IV. BILLING AND ACCOUNTING PROGRAMS

Purpose and Expected Benefits

The second major type of tool for operational efficiency concentrates on billing and accounting functions. Accounting program packages contain one or more of the following modules: general ledger, accounts receivable, accounts payable, payroll, and inventory. General purpose accounting programs may be adaptable to the needs of private waste haulers. Several software producers market a customized accounts receivable module for a general purpose integrated accounting system. These modules recognize special characteristics of private waste hauling such as the distribution of containers and the scheduling of irregular pickups. Generalized public utility billing programs are also available and usually include options for solid waste service billing. Private and public organizations computerize financial accounting to improve administrative efficiency, improve cash flows, and reduce the demand for external accounting services.

Accounting programs require detailed customer, vendor, service, service pricing, asset, debt, inventory, and personnel information before they can be implemented. A general ledger module accepts as its input a chart of accounts for all assets and liabilities. Accounts receivable modules use customer information, service records, and rate structures to prepare bills. Accounts payable routines are used to print checks and log purchases. Payroll modules use work time or productivity records, wage or salary rates, and personnel information to prepare paychecks and log employee work histories.

Once implemented, accounting programs require entry of each transaction, so that accounts remain balanced. Debt service payments, maintenance service bill payment, and payroll transactions must all be entered as they occur. Also, any changes to a customer's or employee's status must be entered to keep records up to date.

Outputs of these programs include lists of customers and their payment histories, printed bills and checks, late account reminder letters, driver's route sheets, and year-to-date transaction histories. Primary outputs take the form of balance sheets and income statements. Some of the more sophisticated programs also produce operating statistics for assessing and improving operational efficiency. Such statistics may include cost profiles for various equipment or labor categories or income projections.

Issues

Accounting programs are operationally simple, but they need precise details, which makes their implementation tedious. Their complexity is highly concentrated in the program set-up phase, because accounts must be balanced before a program can be made operable. Setting up a chart of accounts and defining credit and debit accounts for each type of transaction requires substantial knowledge of accounting procedures. Accounting functions require only simple mathematical operations, which means that outputs are relatively easy to interpret. All of the programs reviewed use menu structures to simplify operations.

In some cases, individual modules can be run independently, which could reduce complexity, but the advantage of automatic balancing of accounts would not be realized. For example, a payroll module could be used independently to produce paychecks or calculate wages without updating the general ledger.

The functional applicability of accounting programs depends upon institutional service arrangements. Integrated utility billing services may be applicable if MSWM services are provided by public agencies that bill separately for MSW services. There are also specialized accounting programs for private waste collection, transport, and landfill operating services.

Institutional arrangements also affect the applicability of income and service tax charges. The flat and variable charge structures usually built into these programs may not be adaptable to local conditions. Also, if billing, purchasing, or payroll processing are carried out by a central agency within the municipality, accounting programs may still be useful, but specialized MSWM packages may not be appropriate.

V. GENERAL APPLICATION SOFTWARE

While general spreadsheet and database programs were not explicitly considered in this review, they can be useful tools for many of the planning and operating functions performed by the programs reviewed. Spreadsheets in particular are simple and valuable tools for economic modeling. In fact, several of the planning programs reviewed were built from these programs (for example, ECO NW Model, REPEP, and SW Financial Model). Both the co-composting model and the waste collection system model developed by the World Bank Infrastructure Department were also implemented on spreadsheet programs.

The beauty of spreadsheets is that input parameters can be viewed and modified merely by scrolling through the spreadsheet and replacing an existing number with a desired one. Also, spreadsheets provide a menu-driven programming environment, along with routines for producing graphs and reports. Once program sophistication reaches the level of iterative loops and conditional calculations, however, the simplicity benefit of spreadsheets deteriorates markedly. Where waste management expertise and computer application familiarity are locally available, the usefulness of spreadsheets should not be overlooked.

General database programs could also produce simple inventory and maintenance record systems. They allow users to create a record structure that includes specific information on each database item. They also include simple routines for searching and sorting database records, and for producing reports. For example, one might create a database that includes the date when each vehicle is next due for inspection. Each day, a maintenance manager could simply search for the current date in the database and report a list of vehicles for inspection that day. This approach does not reduce the need for persistent record updates, but it would allow flexibility to precise local needs if they are understood. Databases are not quite so simple to develop and operate as spreadsheets, but their potential application should be considered.

VI. CONCLUSIONS

The widespread development and use of strategic planning, maintenance management, and billing and accounting programs in developed countries suggests that microcomputer software can improve planning and operation management of municipal solid waste services. The growing availability of inexpensive microcomputers to municipalities in developing countries suggests that in some cases MSWM-related programs could bring about cost-effective improvement in project planning and management in urban areas of developing countries.

Planning programs could provide a framework for strengthening MSWM agencies within a municipality by allowing planners to compare alternative strategies quickly and make prudent investment decisions. Cost savings from more appropriate and efficient use of resources could facilitate extension of MSWM services to currently unserved areas. Planning programs are of highest priority in cities where major investments in MSWM are being considered. The greatest obstacle to applying such programs is likely to be the lack of reliable local data. The "garbage in, garbage out" (GIGO) phenomenon, widely recognized among computer experts, is especially applicable in this context.

The use of customized spreadsheets and other microcomputer programs by planning consultants and development agency staff members further illustrates the potential usefulness of such programs in project preparation and evaluation. Spreadsheets themselves are not a replacement for a well developed planning model, but they could make local development of a simple planning model practical.

The successful application of the "Microcomputer Programs for Improved Planning and Design of Water Supply and Disposal Systems" demonstrates the usefulness of generalized planning programs. An example of this success is reported by the Asian Institute of Technology in a case study of Chonburi, Thailand.[23]

Generally applicable planning programs offer several potential advantages over project-specific computer programs to institutions that may repeat similar analyses in a number of different locations and time periods. In addition to savings that result from improved investment decisions, a generally applicable model could reduce costs of project planning and evaluation by realizing scale economies in software development. The nature of MSWM planning analysis would allow a generalizable, easy-to-use program to be developed once and applied repeatedly with new data for each project area. This is the approach taken by the states of Michigan, New York, and New Hampshire for applying WastePlan at the municipal level. These states license the program and allow unlimited distribution to its municipalities. Similar centralization could work at the regional or national level in developing countries or among projects of the Decade program. Further cost savings could result from a generalized program's ability to focus planning efforts on specific critical issues.

A generalized planning program could also provide a useful training tool for local

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23. Asian Institute of Technology, 1988.

waste managers. If it is comprehensive and easy to use, a generalized planning program could convey the knowledge of experts in a structured format to engineering students or local government trainees. By experimenting with real or hypothetical inputs, users of the model could analyze the sensitivity of MSWM service costs and performance to planning or operating decisions.

Finally, a generalized computer program could serve as the basis of standards. Standardizing the method of project analysis would serve to focus planning efforts and improve the ability of observers to compare projects. It would also allow the development of a standardized database of input parameters such as generation rates and waste characteristics for different regions.

With these benefits in mind, a generalized strategic planning model program could be seen to play an evolutionary role in the World Bank project cycle. If introduced before or during the project preparation stage, the planning program could focus research efforts on the collection of necessary data. Once the relevant data are collected, trained local government officials could use the model to assess current service levels, perform feasibility studies on technical and institutional arrangements, and compare the costs and revenues of alternative project strategies. Following project preparation, World Bank staff could use the model structure to appraise the project and compare it with others. If the project is approved and implemented, the model runs could be compared with actual results for postimplementation supervision and evaluation audits. Having become familiar with the model during project preparation, local waste management planners could continue to use it for future phases of management planning.

Repeated development and disparate use of microcomputer software by development agency staff and consultants could justify a substantial investment in a standard comprehensive program. By providing a standard framework for data collection, project preparation, project appraisal, and postinvestment evaluation, an integrated program could streamline the project cycle for MSWM projects. Where consultants create programs for local application, they should be encouraged to generalize them where possible and to create a legacy of programs and training materials that local government officials could use again as data change over time.

Several easily operated planning programs have been identified that could support planning efforts in developing countries, though none of them perfectly matches the need. It is possible that helpful modifications would add little to program costs, especially of the more expensive programs, or that an integrated program designed specifically for developing countries could be developed.

Where current municipal waste management planning is relatively strong, collection services relatively comprehensive, disposal facilities or sites in good supply, and well educated professionals available, it may be appropriate to optimize facility-oriented programs. In areas where there is an interest in extending collection service, few facilities are used, and the potential new investment is large relative to existing facilities, a simpler (nonoptimizing) evaluation type of program may be most appropriate. Since evaluation programs are easier to understand, require less computing power, and could serve to develop aggregated cost inputs for more advanced optimization programs, this type of program appears to be most appropriate for preliminary evaluations.

In relatively advanced urban areas where spare parts are available and resources for performing preventive maintenance are accessible, maintenance management programs could provide valuable record organization. These are relatively inexpensive and directly address a critical problem of MSWM in developing countries. They could be quite useful for managing equipment and facility records, but they would be justified only if resources necessary to implement their recommendations are available. A computer program that tells managers that all their trucks need new tires would be of little value if tires cannot be afforded. If there is local expertise in database application programming, local development of a simple maintenance program from more general database programs may reduce costs, improve maintenance service, and stimulate local enterprise.

Accounting programs appear to be quite useful and indeed are being used in many municipalities of developing countries, but the lack of international accounting standards reduces the potential benefit of simple generalized accounting programs. In addition, because accounting operations are likely to be centralized, it is unlikely that MSWM agencies within a local government would independently decide to computerize. Compatibility with a central system would be a critical consideration in choosing a customized billing system. Private waste haulers or landfill operators could probably benefit most from customized accounting programs because they have relatively few customers and employees and their services are specialized.

Microcomputer application could serve to strengthen local agencies in some cases. Improved record keeping and more sophisticated planning, besides improving decision making, could indirectly improve the image of local MSWM agencies. Even a simple spreadsheet model or database program could be quite helpful in organizing data and information if properly applied.

As microcomputer technology becomes increasingly available to municipalities in developing countries, it is important that its potential benefits be fully realized. Hardware alone is useless. Software must be available to simplify necessary activities or improve their efficiency. Planning and operation of solid waste management services involve several activities whose tedium and general nature make microcomputer application software a viable consideration.

One of the biggest advantages of computer models is that they demonstrate the need for reliable data collection and indicate the most important data to be collected.

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