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Fuzzy logic based advisory for handling landfill operational problems for early warning and emergency response planning

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Abstract : Day to day operations in a typical landfill involve multitude of tasks. Any error or careless handling may lead to a catastrophic event. To reduce the possibility of such events and assists landfill managers/solid waste personnel, a fuzzy expert system has been developed. This paper details the development of fuzzy expert system as a forethought, for the proposed bio-reactor landfill for city of Dehradun of Uttarakhand. This system christened as "Advisory for Handling Landfill Operational Problems", provides advice as well as early warning and aids development of emergency response plans. Monitored values concerning working conditions at operating landfill gives as input, the fuzzy inference advisor considers the probability of occurence of problems and accordingly provides advice and aids in developing emergency response plan. It aims at providing assistance to inexperienced managers in charge of landfill. It enables managers gain experience, preventing accidents and operational problems in operating landfills. The developed system was validated against several synthetic test cases to check its performance.
Key Words : Fuzzy; landfill operational problems; landfill managers, solid waste.

Introduction

Waste management includes in a broad sense, the collection, transportation and disposal of municipal solid waste. Common disposal methods comprise composting, recycling, incineration, landfilling etc.

Each of these waste disposal methods, essentially being engineering processes, have their own set of operational problems. The consequences of the operational problems in SWM facilities, depending on their nature and severity, range from minor infrastructure damages or simple nuisance problems to critical events, which can lead to the loss of human life or even to disasters. An ''operational problem'' is defined as any situation, during the operation of a facility, which is undesirable from an environmental, economic, social, or an operational perspective. In context of landfills, such operational problems include, the surface and subsurface fires, windblown litter, traffic, leachate and gas management, causing accidents and fatal injuries. An indicative example of a disaster that is related to land disposal of waste is that happened in the Leuwigajah dumpsite in Indonesia, where after 3 days of heavy rainfall, 2,700,000 m^3 of waste started sliding down the valley, killing

147 people[1]. Several types of events like: bad weather conditions, equipment malfunction, wrong operational practices, bad equipment design, human, organizational and communication errors,individually or in combination lead to critical operational problems and disasters. Unfortunately, there is a gap in existing knowledge with respect to the factors that contribute to the occurrence of incidents and accidents in SWM facilities. This puts forth a need to collect, comprehend and classify this knowledge in order to develop a system which can ultimately provide an efficient advisory for landfill operational problems.

The section below presents a partial list of landfill operational issues and some of their preventive aspects.

Landfill operations and related issues

Operating procedures at a sanitary landfill are influenced by many factors, many of which are site-dependent. The landfill operations plan, prepared as a part of landfill design process, serves as primary resource document, providing the technical details of the landfill and procedures for constructing various related equipment. This document should be consulted regularly to assure conformance with the plan. While commonly overlooked in landfill construction, documentation can be invaluable when questions arise in the future regarding the adequacy of site construction. Documentation also proves greatly useful while justifying to regulatory authorities and local committees that appropriate design standards have been employed and utilized, before the commissioning.

Waste disposal being primary purpose of a landfill, movement and compaction of waste are essential sub processes involved. Waste movement is usually confined to the spreading of waste on the working face. Compactors or dozers are used for this purpose, after trucks have deposited it. This spread is made to a limited distance.

Periodically, usually daily, the compacted waste is covered with earth and a new cell is started. An alternative to soil cover is the use of manufactured foams or temporary blankets, facilitating waste deposit spread at the top of the working face. A drawback of this method is the problem of litter control.

Degree of compaction is a critical parameter for extending the useful life of a landfill. For achieving high in-place waste densities, a compactor may be necessary. The number of passes that the machine should make over the wastes to achieve optimum compaction depends upon various factors like machine wheel pressure, waste compressibility, land and fuel requirements, labour costs, and work load.

The working face slope will also affect the degree of compaction achieved. As the slope increases, vertical compaction pressure decreases.

1. Weather conditions form an important factor affecting landfill operations
2. For example: Extreme cold weather causes trouble in starting and operating machinery.
3. Additionally, staff comfort due to unavailability of appropriate clothing can be an issue demanding immediate attention.
4. Recommendations from equipment manufacturers, concerning cold weather operation of equipment, facilities to operating staff etc. can mitigate this problem to some extent. Problems in rainy season are especially serious with soils that have high silt or clay content. When wet, these soils become very muddy, and provision should be made to continue operation in areas of the fill that are less susceptible to problems. Wet weather plans should include measures to reduce tracking of mud from the landfill onto the road system and provisions for cleaning trucks.

Litter and fire control

Litter does not seriously damage the environment, yet it is perhaps the most persistent operational problem cited by surveys. Its seriousness is due, in part, to bad public image. Waste discharging procedures, orientation of the working face to the wind, absence of wind shielding features near operation site, and waste type and preparation all play a role litter related problems. Unloading wastes at the bottom of the working face can help. Here the wind cannot pick up materials as easily as when wastes are deposited at the top of the working face.

Dust can also be a nuisance at landfills, both to employees and neighbours. Water wagons can be used to control dust. Calcium chloride is also used for dust control, since it absorbs moisture from the air.

Fires within the waste are best controlled by digging out the combusting material and covering it with dirt. A fire extinguisher is a must item for every equipment operating staff. Expensive pieces of operating equipment should be protected with automatic fire detection and suppression equipment. Water wagon equipment can be used for fire control. Also, arrangements should be made with local fire-fighters to establish procedures for extinguishing landfill fires.

Human Input

To maintain an efficient landfill operation, staff must be carefully recruited, trained, and supervised. Well-trained staff are a key to efficient landfill management. Staff include equipment operators, maintenance personnel, a scale operator, labourers, and a supervisor. Staff are also appointed for maintaining documentation regarding financial and other day to day MIS details. The landfill manager should hold reasonably years of experience in operation of landfill. Additionally, should be provide technical and managerial training for enhanced workmanship. Several institutions and associations conduct training courses for landfill operators.

Accidents are preventable

Accidents are expensive, with hidden costs often several times more than the readily apparent costs. Solid waste personnel work in all types of weather situations, with many different types of heavy equipment, with a variety of materials presenting diverse hazards, and in many different types of local settings.

The types of accidents possible at landfills include direct injury from explosion or fire; inhalation of contaminants and dust; asphyxiation due to workers entering a poorly vented leachate collection system, manhole, or tank; falls from vehicles; accidents associated with the operation of heavy earth-moving equipment; attempting to repair equipment while the engine is operating; exposure to extreme cold or heat; or traffic accidents at or near the site. The developed system would aid the landfill personnel in preventing such accidents. This advocates the need for the development of a landfill advisor which along with giving advice would work as an early warning system. The landfill advisor has been developed as part of project expert system for integrated solid waste management and has been integrated under its planning module.

Literature review

Factors affecting Landfill failure

Athanasopoulos, G., *et al.*[2] based on the study of data collected following the slope failure at the Xerolakka Municipal Solid Waste landfill in Greece, concluded that the failure was amplified by the combined effects of various factors. These factors include inappropriate waste disposal practices, inadequate compaction, leachate and gas pressure generation and increased steepening of the landfill slopes. The analysis also indicated that rainfall was the major expediting factor, stating that the failure would not be incipient under dry conditions.

Towhata[3] studied collapse of MSW landfill in Bandung City, Indonesia and based on analysis of collected data collected, reported issues and problems such as heavy rainfall, improper waste disposal leading to landfill failure. The paper emphasises on the need for safety in landfill operations and management. It also advocates the need for a warning system that facilitates the better handling of the landfill operations and efficient management of environmental and mechanical risks.

Dunnet[4]based on his investigations, highlighted the various issues with South Fremantle landfill site including landfill gas production, groundwater contamination, waste settlement, health hazards and potential of explosion.

Stark *et al.*[5] based on their investigations of landfill slope failure, have concluded the role of factors such as reappearance of cracking, 3D stability analysis, stress, strain, leachate generation, surface water flow and slope angle in MSW landfill slope failure.

Landfill operational problem

Chun *et al.*[6] studied adverse influence of landfill gas on the climate in and around Sudokwon landfill site, Korea. Additionally, they analysed the amount of methane gas generated from the landfill. They concluded that for improving landfill method as a waste treatment methodology better adapting to climate change, the research and development on the intermediate covering system along with the fundamental enhancement on present landfill facility establishment standards and operating guidelines are required.

Rowe [7] discussed issues concerning landfill operations viz. landfill cover, waste placement, leachate recirculation, liner temperature, leachate characteristics, liner leakage, performance of geomembranes etc. Based on analysis concluded that the adoption of a systems engineering approach for the design, construction and operation of MSW landfill minimise the environmental impacts of landfill with focus on performance of the system as a whole instead of singular components.

Chen *et al.* [8] focused on the geotechnical issues concerning waste and leachate flow, landfill gas generation, settlement of landfill, stability of waste mass etc. The major concern with current landfill practices in China has been emphasized upon.

Depountis*et al.* [9] reported various environmental problems associated with the development and operation of MSW landfill based on their study of two existing landfills in Greece. They emphasized upon the recirculation of leachate as a better engineering practice.

Pivato[10] illustrated upon a suitable methodology for the evaluation of landfill liner failure viz. deductive analysis and predictive analysis, comparing both and presented results too conservative and not close to what would actually occur in reality.

Townsend *et al.*[11] compiled their observations in the form of a manual to serve as a guide/reference to design, construct and monitor operations of a bioreactor landfill. Special emphasis has been placed upon leachate recirculation facilitating the waste decomposition process. They suggested development of bio-reactor landfill as solution to issues such as high rainfall and leachate management control and monitoring were suggested to be better managed through SCADA systems.

Ling *et al.* [12] formulated equations for the determination of the factor of safety of landfill soil cover to seismic conditions. They concluded that finite slope analysis in comparison to infinite slope analysis has significant effect on the stability. The other factors that are influential were slope geometry, soil geomembrane direct sliding co efficient, and adhesion, length and thickness of the soil cover.

Foping*et al.* [13] presented a need for early warning system through a software tool.

Dokas*et al.* [14]developed a Landfill operation management advisor (LOMA) an expert system that uses techniques fault tree analysis and fuzzy inference. The system provided early warning and emergency response and served as an aid to landfill managers.

The work reported in this paper presents design, development and working of a landfill advisor module, which has been developed as a part of integrated solid waste management expert system. This system has been developed for city of Dehradun, in Uttarakhand state and is being strongly recommended for use especially in the current context with local authorities planning a landfill for the city. With landfill in planning stages, such an advisor cum early warning system is highly relevant and useful tool in assisting the inexperienced manager for the management of the entire landfill operations and also reduces the chance for catastrophe. An earlier research study by the authors recommended a bio-reactor landfill due to the type of waste abundant in the waste samples collected for this metropolitan. Therefore the sections below present landfill operation challenges, diagnosed problems and possible solutions, advise, in context of bioreactor landfills.

Operational problems

The day to day operation of a bioreactor landfill is complex and involves several processes. Each of these processes depends upon various factors. Any deviation from the norm creates a multitude of problems that affect smooth running of the landfill. A partial list based upon the information gathered in the knowledge acquisition phase of the development of the landfill advisor has been provided category wise in the table A-1 in

Annexure A. Additionally there are problems faced by landfill staff, which have been not taken in the current scope.

The current scope of this paper is limited to landfill operational problems having been prioritized by landfill experts as most influential and have maximum impact on the working of the landfill. Further this selection has been validated against the sources of literature prominently the solid waste management manuals accepted in various countries. These have been identified as a set of root problems for the development of the landfill advisor.

Table 1: List of operation problems selected

Problem Category	Operational Problem
Miscellaneous problems	Surface fire
	Subsurface fire
	Uncontrolled storm water runoff
	Rainy weather
Leachate related problems	Leachate collection and drainage system failure
	Overflow of leachate collection holding ponds
	Leachate seeps
	Leachate holding ponds about to fill/ overflow
Human related Problems	Landfill Machinery hit person
	People with cigarettes in the work face
Environment	Odour
	Gas Migration
Landfill Liner	Liner leakage
Landfill Gas	High Methane generation

Parameter selection

Each of the selected operational problem is affected by various environmental factors and amongst these some of the factors play a very critical role and thus have been chosen as decision parameters in system development.

Table 2: Decision Parameters

Problem Category	Operational Problem	Decision parameters
Miscellaneous problems	Surface fire Subsurface fire Uncontrolled storm water runoff Rainy weather	Phase completion Landfill Gas, Air in Landfill Rainfall Rainfall
Leachate related problems	Leachate collection and drainage system failure	Leachate
	Overflow of leachate collection holding ponds Leachate seeps Leachate holding ponds about to fill/ overflow	Leachate Rainfall, Temperature in Landfill Leachate
Human related Problems	Landfill Machinery hit person People with cigarettes in the work face	Human Efficiency Incinerating devices
Environment	Odour Gas Migration	Gas, Air Quality Index Gas, Leachate
Landfill Liner	Liner leakage	Leachate, Water Quality Index
Landfill Gas	High Methane generation	Gas

Further reference to landfill operational manuals[15,16,17,18,19].

Technology Used

The advisor has been developed as a fuzzy inference Expert system. Flex's expert system tool, and 'Flint tool kit have been used for development.

The main purpose of the advisor is to act as (a) a useful tool for the inexperienced landfill manager, because it correlates events that are common during landfill operations, anticipate probable problems and generate advise as applicable (b) Reliable tool , ensuring reasonably closer anticipation of the problems as per operational. A user friendly interface has been developed to ensure ease of use and promote accessibility amongst target users. The section below presents a description of the advisor, shows its procedure of working, in terms of methodology use to evaluate the current operational conditions using identified decision parameters and display early warning and advice as applicable. The fuzzy logic approach of computing has been used for this development.

Fuzzy membership functions

The decision parameters are monitored regularly in and around an active landfill in real time. These values are expected to be entered by the landfill manager in the landfill advisor. These are assigned membership functions and are fuzzified for further process.

The table below presents the major considerations provided for the parameters.

Table 3: Parameters as input/output

Sr. No	Parameter	Unit	Input parameter	Output Parameter
1	Temperature	˚C	Yes	No
2	Rainfall	mm	Yes	No
3	Air Quality Index (AQI)		Yes	No
4	Air (inside landfill)	%	Yes	No
5	Efficiency (Human)	%	Yes	No
6	Incinerators (in human possession)	%	Yes	No
7	Phase Completion (Active part)	%	Yes	No
8	Water Quality Index (WQI)		Yes	No
9	Landfill Gas		Yes	Yes
10	Leachate		Yes	Yes
11	Surface Fire	Probability	No	Yes
12	Subsurface Fire	Probability	No	Yes
13	Odour	Probability	No	Yes
14	Gas Migration	Probability	No	Yes

The membership function defined for the fuzzy variable temperature has been shown in the (Figure 1). Specifically for the bio-reactor landfill available literature has been taken for reference for ascertaining ranges and end points for the membership function[21,22]. Similar process has been used for making fuzzy membership functions for all the other fuzzy variables [15,16,17,18,19,20,23,24,25,26,27,28,29,30].

```
fuzzy_variable temperature ;
     ranges from 0 to  70 ;
     fuzzy_set low is \ shaped and linear at 20, 30 ;
     fuzzy_set medium is /\ shaped and linear at 20, 40, 50 ;
     fuzzy_set high is / shaped and linear at 40, 50 ;
     defuzzify using
         all memberships
         and mirror rule
         and shrinking .
```

Figure 1: Fuzzy membership function for temperature fuzzy variable

Once the membership functions have been defined, the fuzzy associative memory is created for the output fuzzy variables to aid in inference making. (Figure 2) presents one such example for leachate generation.

```
% FAM - Fuzzy Associative Memory

fuzzy_matrix leachate_value
  temperature  *  rainfall  ->  leachate      ;

     low          *  low       ->  low          ;
     low          *  medium    ->  low          ;
     low          *  high      ->  medium       ;

     medium       *  low       ->  low          ;
     medium       *  medium    ->  medium       ;
     medium       *  high      ->  large        ;

     high         *  low       ->  medium       ;
     high         *  medium    ->  large        ;
     high         *  high      ->  large        .
```

Figure 2: Fuzzy associative memory

Expert system

The developed landfill advisor uses a data driven programming approach. Landfill manager is expected to provide input, as per the details obtained from the real time monitoring of landfill site. The Landfill advisor developed as a component of the integrated SWM Expert systems is a fuzzy logic based inference system. It infers decisions based upon the inference provided by the use of fuzzy logic, subject to input of the monitored data by the landfill personal. The monitored data i.e. crisp values are then converted into fuzzy values based on the membership functions.

The workflow

The landfill advisor presents a set of questions to the landfill manager to gather input concerning current operating conditions within the landfill. The landfill manager is prompted to enter the monitored values.

The input values are converted into fuzzy values by means of a fuzzy membership function (fuzzification). After the fuzzification the input values are passed back to integrated SWM Expert System (ISWM).

As more than one operational problem could occur at a time due to a dynamic change in the values of the monitored parameters, a few parameter values are calculated by defuzzification process and passed to ISWM expert system. This stage is repeated till a value is available for each one of the causal parameters taken into consideration in this case.

Based on the values retained by the combination of various causal parameters and the combined range in which they fall, the expert system activates the inference engine for use of the forward chaining methodology to arrive at a particular conclusion.

Once the goal is reached by the ISWM expert system, based on the fuzzy values of the causal parameters an appropriate response is provided to the landfill manager regarding current operational conditions and likely problems that may occur, probable causes and corrective action along with suitable advice that the manager could follow.

Referring to the scenario, each advice corresponds to a specific basic event. Also, the corresponding solutions are displayed rank-wise based on the fuzzy importance measure value of each basic event. Further, the system informs the user if the analysed problem could possibly generate any other operational problems.

Evaluation of the system

The landfill advisor has been tested using various test cases and its performance evaluated. The database of test cases comprised of synthetic events and actual emergency situations from the past. Monitored values were provided as part of test cases to the landfill advisor. The response by the advisor for real time scenarios displayed early warning and results as expected in accordance with the handling by landfill experts.

The advisor was able to identify more than 80 percent of the causes and the early warning signals as stored in the knowledge base of the expert system. The scope of present work does not cover factors related to human error.

Results and discussion

The Landfill Operation Advisor was test run, the results of which have been shown in the following sections. The complete flow of execution of the landfill advisor through different test scenarios is shown in following sections through a sequence of screen shots.

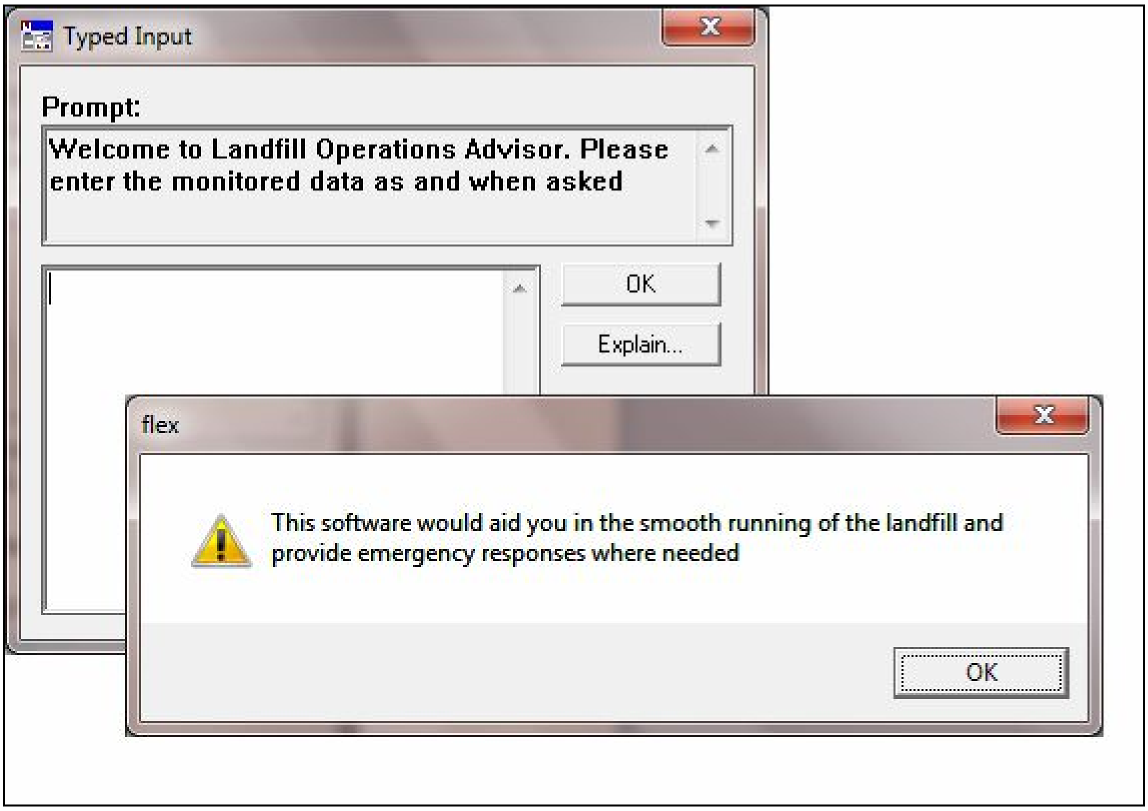

Figure 3: Landfill Advisor Welcome page

Questions Asked

The set of questions asked haven been shown in the following figures.

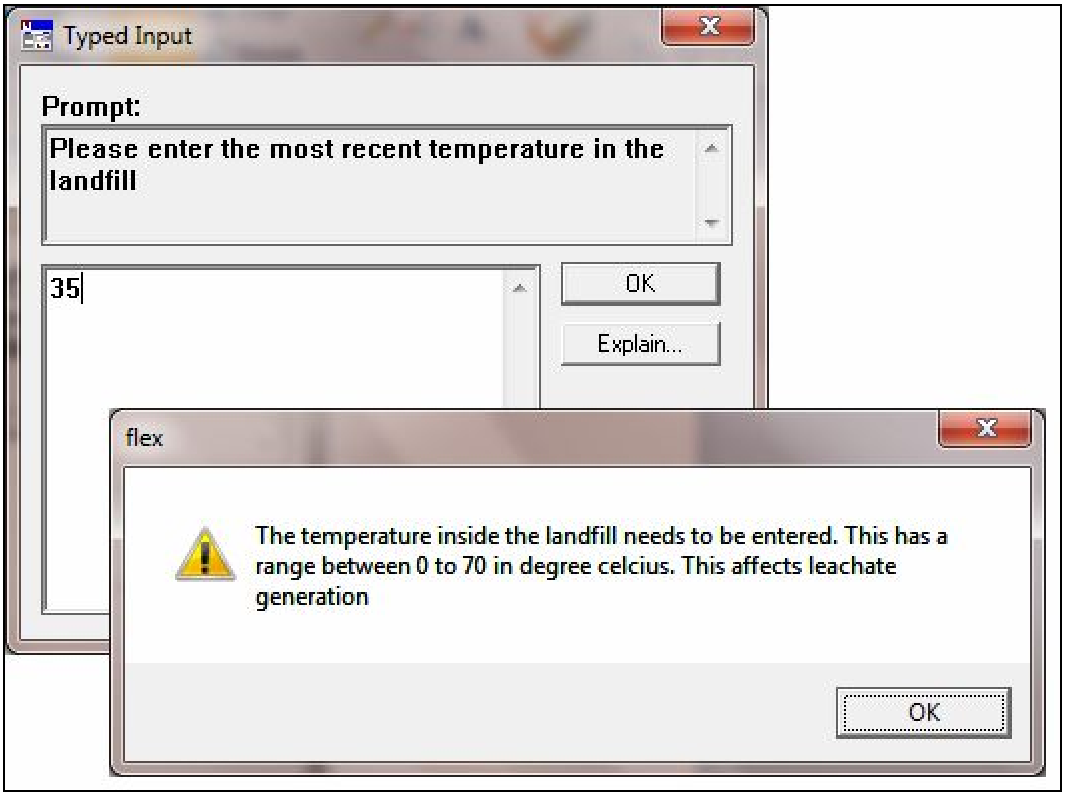

Figure 4: Question- temperature variable

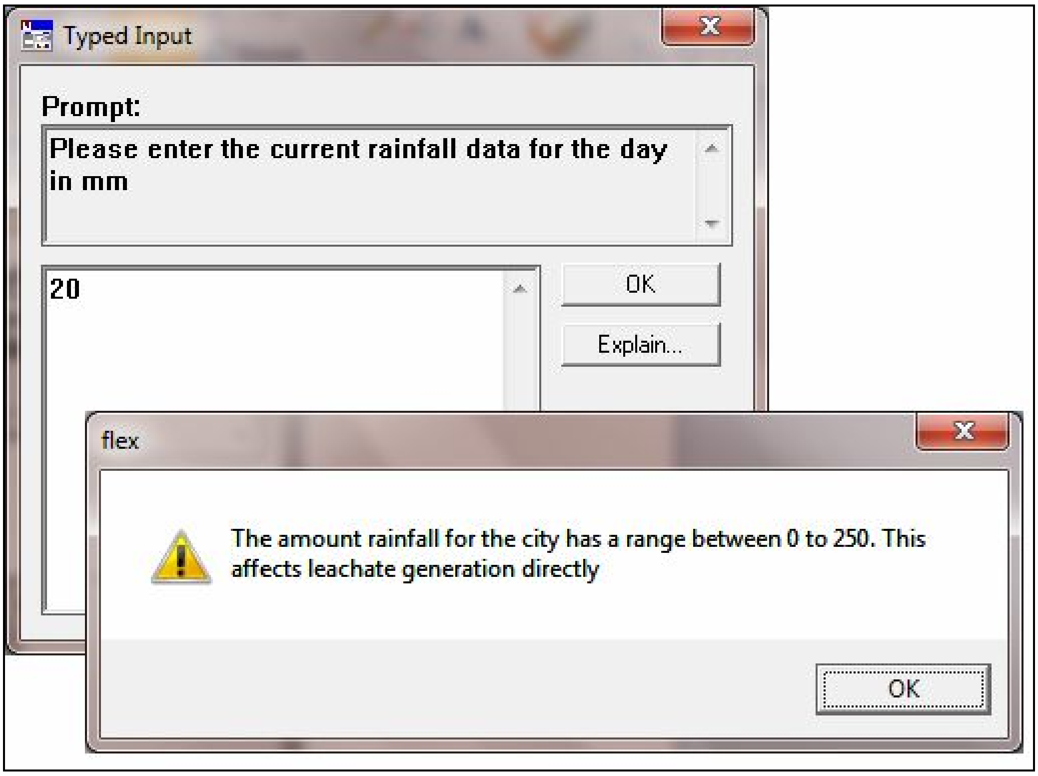

Figure 5: Question- Rainfall variable

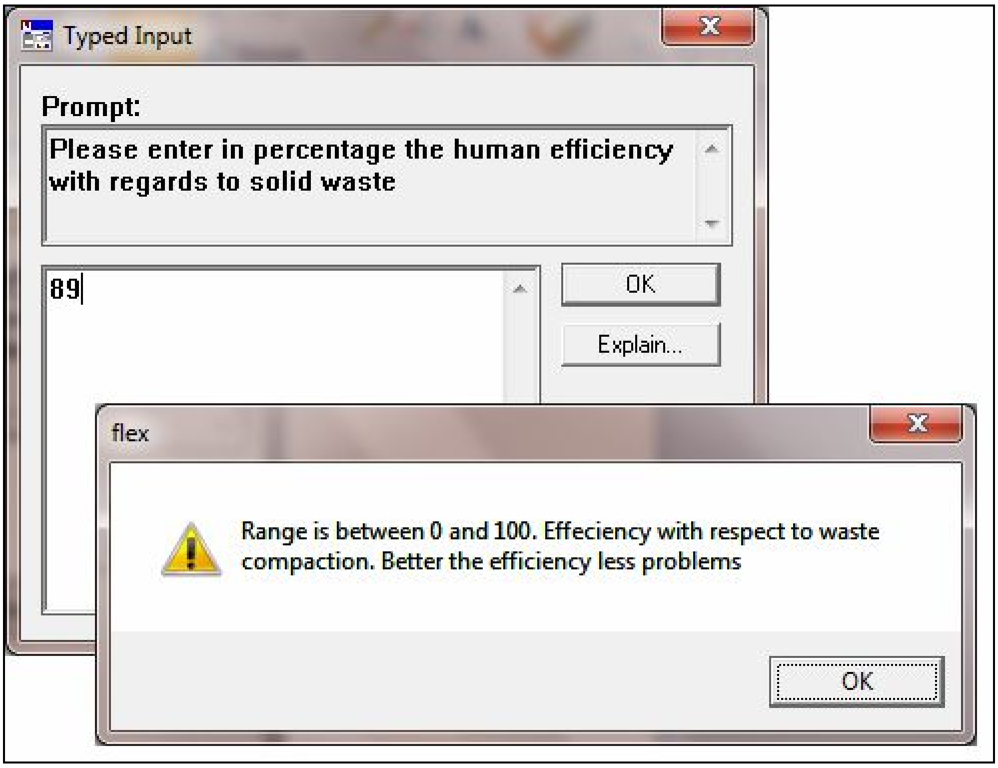

Figure 6: Question- human efficiency

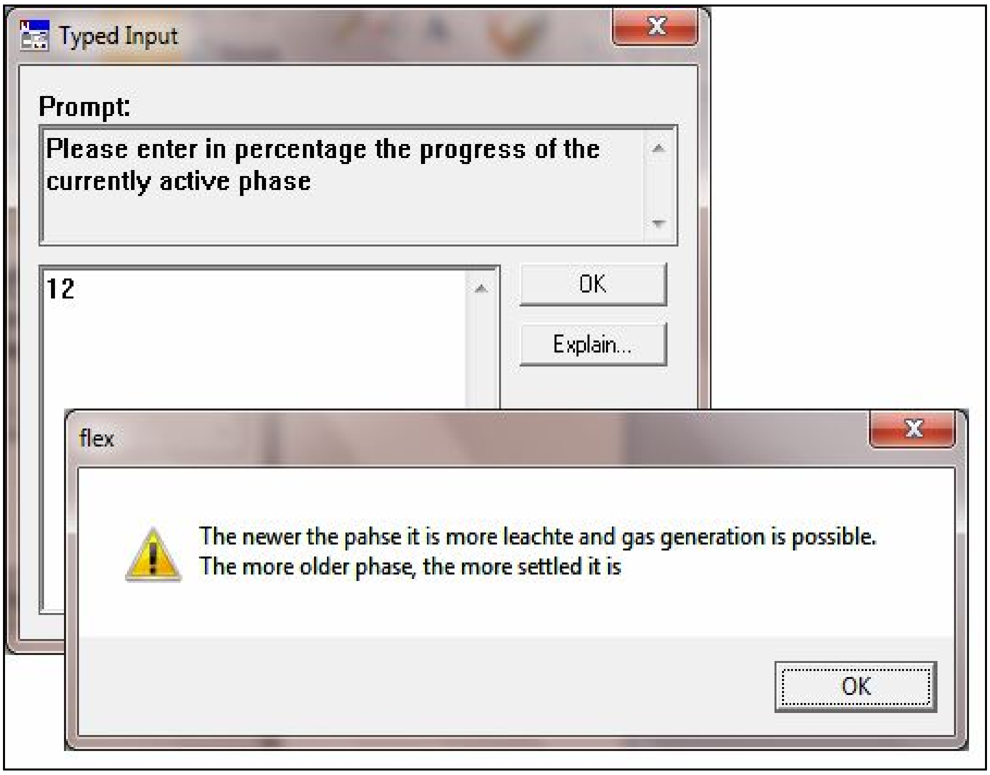

Figure 7: Question- Active Phase

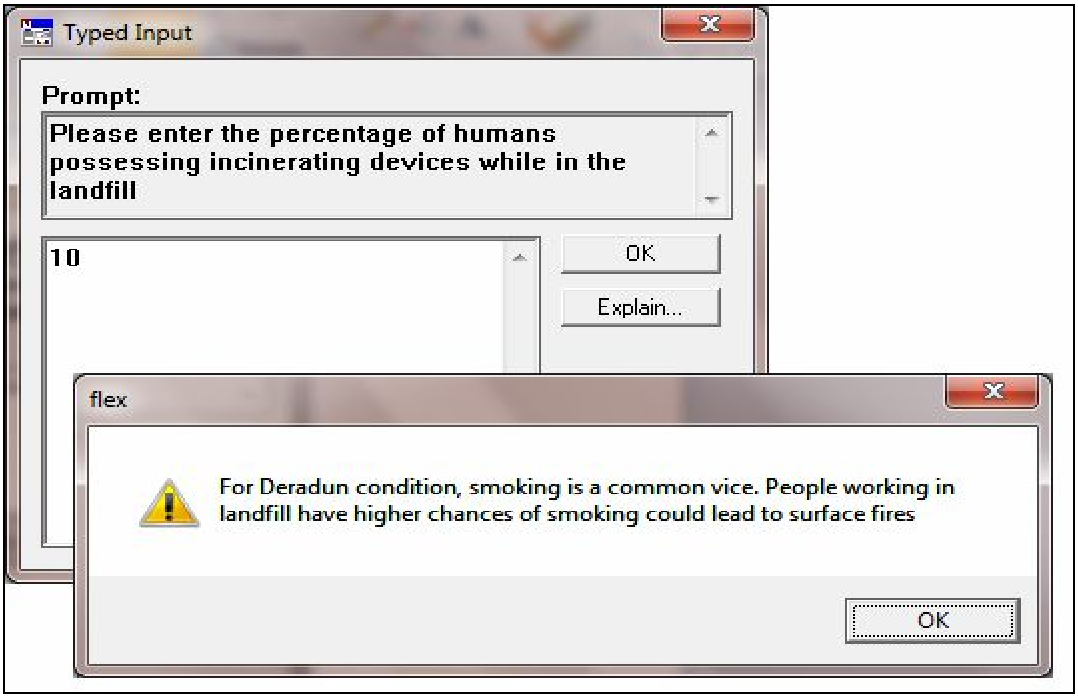

Figure 8: Question- Incinerating Devices

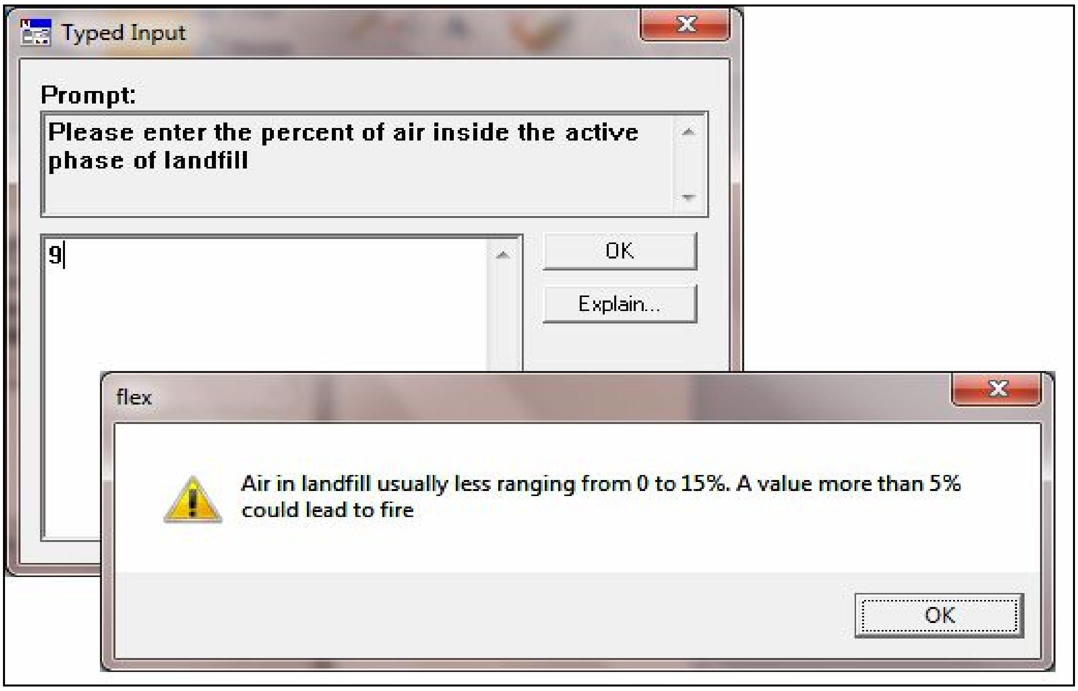

Figure 9: Question- Air in landfill

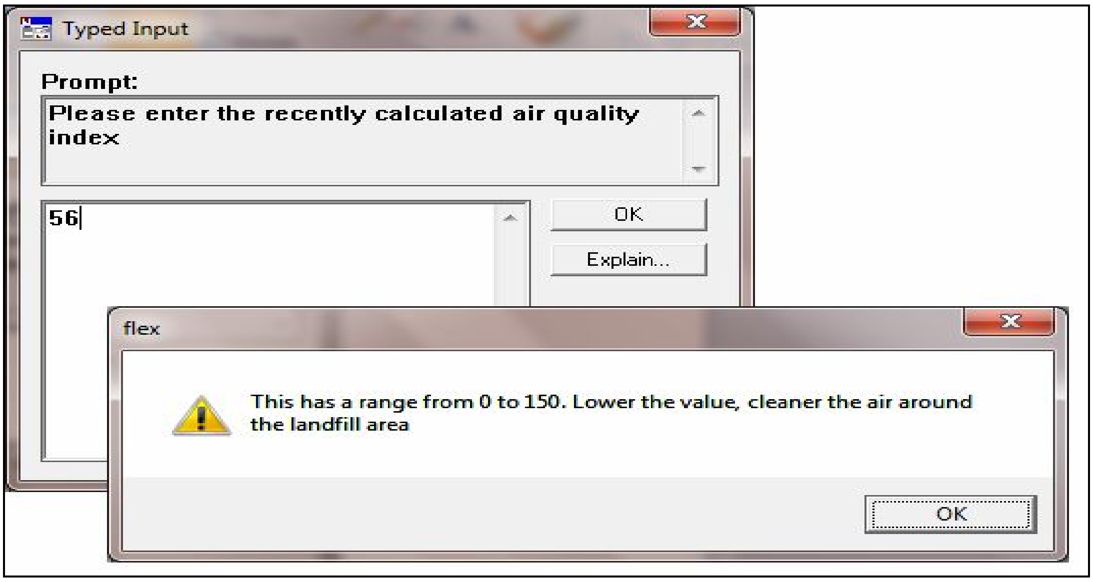

Figure 10: Question-Air quality index

Output

```
| ?- landfilloperation.
Input of monitored values:The current landfill temperature is: 35
The current rainfall is: 20
The current air quality index is: 56
The current amount of air inside landfill is: 9
The current human work efficiency for solid waste is: 89
The current landfill phase completed percent is: 12
The current usage of incinerating device by humans is: 10

the calculated values are:The current leachate generated is: 0
The current landfill gas generated is: 1247.4358974359
The current probability of a surface fire is: 54.1666666666667
The current probability for a subsurface fire is: 50
The current amount of odour from landfill is: 45
The current probability of gas migration is: 60
emergency response category :surface fire
 advice: bury the buring material in a separate pit and cover it
emergency response category :sub surface fire
 advice: insert liquid inside
```

Figure 11: Output

Conclusion

The objectives of this system in the framework of the SWM industry is the provision of timely warning of imminent dangers so that the managers and personnel could have time to prepare their strategy and actions accordingly to prevent it. This has been achieved by the combination of the technologies of Expert System (ES) technologies together with basic principles of the theory of fuzzy logic to develop a EWS for landfill operations.

The main characteristic of the advisor is that of the use of frames as knowledge modelling and representation and fuzzy logic for reasoning technologies. This allows the advisor to assess the possibility of the occurrences of operational problem and provide valuable advice that includes corrective actions and emergency response procedures for the mentioned operational problems.

These actions can be implemented not only by the personnel of the organization at the tactical and operational levels to avoid or to reduce their risk and to be prepared for effective response but also by the people living close to landfills, which are affected by their operations.

This prototype being specifically designed for Dehradun conditions was able to satisfactorily provide results as expected by the landfill expert. This software could further be worked upon for the inclusions of more problems and the changing landfill environment as pertaining to a bioreactor landfill.

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ANNEXURE A

Landfill Operational Problems:

This annexure contains the table containing the list of all operational problems.

Table A- 1: Landfill Operational Problems

Categories	**Problem**
Environment	Dust
	Vector-Rodents
	Water Ponding
	Insects
	Litter
	Odour
	Noise
Working Area and Perimeter	Wide working front
	Working front near landfill border
	Soft spots in the working front
	Wires tipped in working front
	Bulky waste tipped in working front
	Low litter fence performance
	Perimeter fencing problem
	Small distance between the landfill reception and the public roads
Transportation Problems	Wheel cleaning facility problem not available
	Delays during unloading of the collection vehicles
	Mud and debris on the public highway
	Obstructed movement of collection vehicles
	Dry dirt roads
	Inadequate road width
	Muddy roads
	Potholes in the road
	Rutty road
	Steep point in the road
Infrastructure problem	Landfill machinery damage
	Machinery without backup warning device
	Problem with compactor operator
	Problem with loading machinery
Waste problems	Waste mixture problem during compaction
	Large height of waste layering during compaction
	Inefficient lead checking
	Waste disposal in wrong place
	High discharging waste point
	Prohibited waste tipped in the landfill
	Unsatisfactory waste compaction
	Offensive/Malodorous wastes
	Cannery waste
	Dusty incoming waste
	Lightweight incoming waste
	Dead animals
	Seaweed
	Sludge

	Incoming smoking/ burning loads
	Uncontrolled appliances/demolition waste/ tires
Cover problems	Depression in the surface of the landfill
	Lift slopes problem
	Potholes in the fill
	Sink holes on the landfill surface
	Unavailability of waste cover material
	Erosion cuts of the landfill cover
	Impermeable intermediate cover layer
	Partially covered/ uncovered waste
	Waste covering activities
	Waste cover compaction problem
Human related problems	Landfill machinery hit person
	Unauthorized people in tipping area
	Human activities near the landfill
	Problem with excavation machinery operator
	Problem with gate keeper
	Problem with landfill night guard
	Problem with landfill truck drivers
	Problem with leading machinery operator
	Problem with the spotter
	People with cigarettes in the work face
	Unauthorized people in the landfill
Landfill gas related problems	No available gas combustion facility
	Overdrawing of landfill gas extraction wells
	Problems with gas combustion facilities
	Smoke or combustion gasses escapes out of fissures
Leachate related problems	Leachate collection and drainage system failure
	Overflow of leachate collection holding ponds
	Leachate seeps
	High leachate levels above liner
	Large filling rates of leachate holding ponds
	Leachate holding ponds about to fill/ overflow
	Leachate holding ponds without aeration or chemical treatment/ cover
Miscellaneous problems	Surface fire
	Subsurface fire
	Uncontrolled storm water runoff
	Rainy weather
	Warm weather
	Windy weather conditions

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