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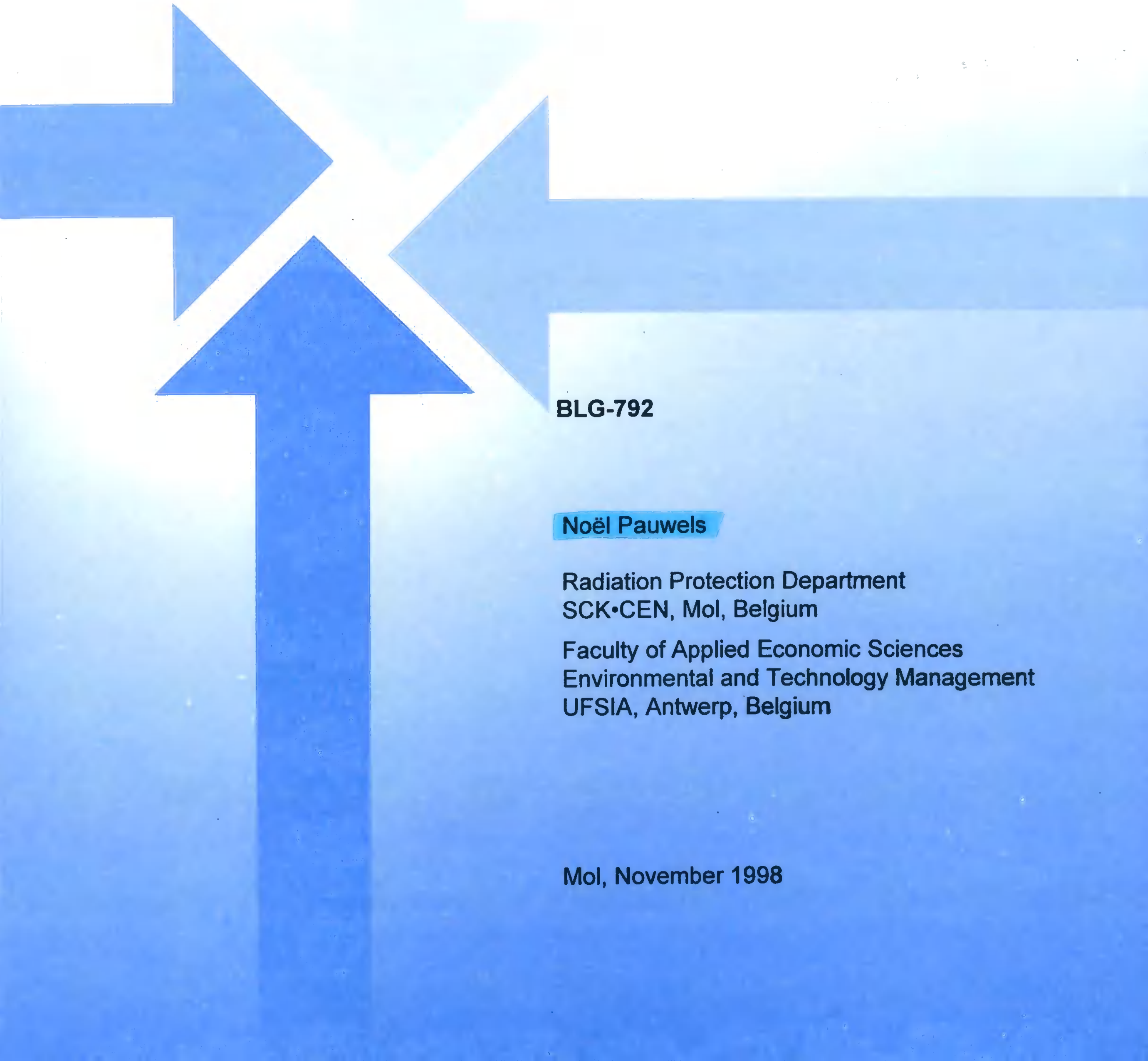
ERDOS 1.0

Emergency Response Decisions as problems of Optimal Stopping



BLG-792

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Mol, November 1998

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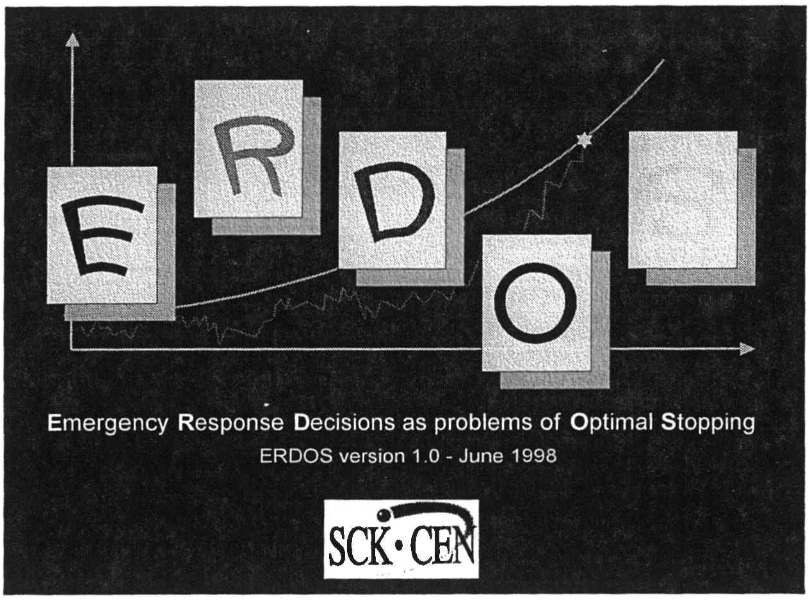

Emergency Response Decisions as problems of Optimal Stopping
ERDOS version 1.0 - June 1998
SCK•CEN

BLG-792

Mol, November 1998

ABSTRACT

The ERDOS-software is a stochastic dynamic program to support the decision problem of preventively evacuating the workers of an industrial company threatened by a nuclear accident taking place in the near future with a particular probability. ERDOS treats this problem as one of optimal stopping: the governmental decision maker initially holds a call option enabling him to postpone the evacuation decision and observe the further evolution of the alarm situation. As such, he has to decide on the optimal point in time to 'exercise' this option, i.e. to take the irreversible decision to evacuate the threatened industrial workers.

ERDOS allows to calculate the expected costs of an optimal intervention strategy and to compare this outcome with the costs resulting from a myopic evacuation decision, ignoring the prospect of more complete information at later stages of the decision process. Furthermore, ERDOS determines the free boundary, giving the critical severity as a function of time that will trigger immediate evacuation in case it is exceeded. Finally, the software provides useful insights in the financial implications of 'loosing' time during the initial stages of the decision process (due to the gathering of information, discussions on the intervention strategy to be followed, etc.).

KEYWORDS

binomial trees, decision making under uncertainty, nuclear emergency, optimal stopping, real options.

JEL-CLASSIFICATION

C61, C88, D80, G13

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1 Introduction

The decision problem of preventively evacuating the workers of an industrial factory in case it is threatened by a nuclear accident taking place with a particular probability in a nuclear power plant nearby, is treated as one of optimal stopping. The governmental decision maker initially holds a call option enabling him to postpone the evacuation decision and obtain further information on the course of the alarm situation. As such, he has to decide on the optimal point in time to 'exercise' his option, i.e. to take the irreversible decision to evacuate the threatened industrial workers.

The time-horizon of this decision problem clearly is finite: within a reasonable period of time, either a release effectively takes place, or either the alarm is ended as the situation in the nuclear power plant is again under control. Moreover, the call option is American as it can be exercised at every single point in time (and not only at maturity). As such, an analytical closed-form solution cannot be obtained [5, 7].

However, two strategies can be followed to value a finite-lived American call option. First, an analytical solution can be found under the assumption that the option is infinitely lived [5, 11], implying in our decision context that the nuclear alarm may be everlasting. This strategy will result in an exact solution to an approximate decision problem. Secondly, the finite time-horizon can be divided in a limited number of time-intervals of equal length. An approximate (discrete) solution to the exact decision problem can then be obtained by using a numerical method: finite difference methods, lattice techniques, Monte Carlo simulation [4, 12].

This paper discusses the ERDOS (Emergency Response Decisions as problems of Optimal Stopping)-software that follows the latter approach and makes use of a binomial tree (lattice) to deal with the preventive evacuation decision problem.

ERDOS can be used to calculate:

- the expected costs of following an optimal intervention strategy as opposed to the costs resulting from a myopic evacuation decision, ignoring the prospect of more complete information at later stages of the decision process;
- the free boundary of the decision problem, i.e. the critical level of the severity of the release as a function of time that will trigger immediate evacuation in case it is exceeded;
- the financial implications of 'loosing' time during the initial stages of the decision process.

The remainder of the paper proceeds as follows.
The decision context of preventively evacuating the workers of an industrial company in case of a nuclear emergency, is discussed in the next section. Section 3 introduces the models and solution methods used in the software. Section 4 briefly shows how to use ERDOS, while some illustrative outputfiles are presented and discussed in section 5. Section 6 contains some program-technical information on the software. Section 7 concludes. A list of the inputparameters and variables used in the software is included in Appendix 1 and 2 respectively.

2 Decision settings

Suppose a nuclear power plant (NPP) emergency manager alerts the government at t_0 that an initiating event (e.g. a significant increase in reactor temperature or pressure) has occurred that might possibly escalate in the near future and result in a radiological release into the environment. As the workers of an industrial company in the immediate surroundings of the affected NPP are threatened by the alarm, the government has to decide on their preventive[1] evacuation. The objective function consists in minimising total expected costs.

Furthermore, suppose the NPP emergency manager is able to provide the following information to the government:

- An estimate of the severity of the release in case it occurs at the time of the initial alarm t_0, i.e. $\mathbf{x_0}$. This severity x_0 is expressed as the resulting collective dose for the workers of the industrial facility nearby.
- The uncertainty σ with respect to the evolution of this estimated severity.
- The expected duration of the threat **T**: if a release has not occurred before time T, it is assumed that the situation is under control and that there will be no release at all.
- The probability $\mathbf{p_t}$ of the release effectively taking place in time period t, given that a release has not yet occurred in the previous time periods. For simplicity's sake we assume that the probability of the release taking place is constant during the threat and zero - by definition - afterwards (Fig. 1). As such,

$$(1) \qquad \begin{cases} p_t = p, & \forall t \leq T; \\ p_t = 0, & \forall t > T. \end{cases}$$

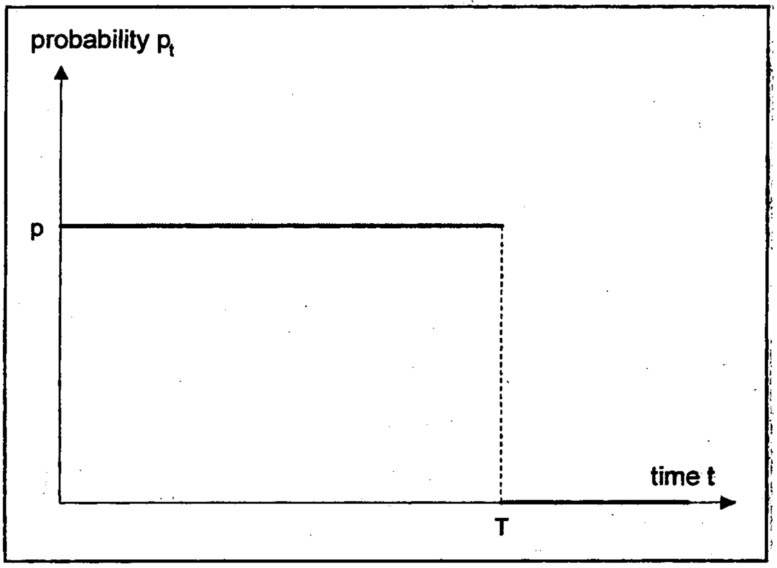

Figure 1. Probability of the release taking place as a function of time.

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[1] Note that we assume that evacuation is a purely preventive countermeasure: once a release has occured, it may no longer be desirable to evacuate the workers. This is for instance the case when the release only consists of noble gasses: after the radio-active cloud has passed, the doses still obtained by the workers will be negligibly small.

Besides this information related to the nuclear alarm, the government obtains the following information from the threatened industrial company:

- The added value per unit of time C_{ad} that would have been generated by the company under normal working conditions.
- The costs of shutting down the industrial installations, C_{sd}. This unforeseen shut-down may result in the loss of products-in-process[2] or may cause considerable damage[3] to the reactors [6, 9, 10]. Depending on the model that is used (cf. infra), a distinction is made between a fast and a slow shut-down mode. In case of a fast shut-down the production processes will be stopped as fast as possible with respect to the safety of the workers, without taking into account, however, the economic implications of this shut-down. In case of a slower shut-down, however, both the safety of the workers and the economic implications of this shut down will be taken into account.
- The costs of restarting the industrial facilities after having been shut down, C_{su}. These costs refer to the continued (partial) loss of added value during the start-up phase of the production processes, the potential loss of market share, etc [1]. Again a distinction is made in model 3 between the costs of restarting after a fast and after a slow shut-down.

  Note that also other costs (transportation, accommodation, etc.) may result from the evacuation decision. However, in general these 'traditional' evacuation costs will be small compared to the costs resulting from shutting down the industrial production process.
- The time T_{sd} needed to shut-down the industrial processes. Model 1 assumes that no time is needed to shut-down the facilities. Model 3 again distinguishes between a safe and fast shut-down on the one hand (duration: T_{sd_f}) and an economic and slower shut-down on the other hand (duration: T_{sd_s}, with $T_{sd\_s} > T_{sd\_f}$). It is assumed that during the execution of the shut-down, the number of workers present at the industrial site decreases linearly over time (Fig. 2).

Furthermore, the following general information is required:

- A discount rate [3] to express both time-preference and risk-aversion. This discount rate is needed to calculate the costs associated to the evacuation 'option' on the one hand, and the costs associated to the evacuation decision on the other hand. Whereas the risk-neutral discount rate can be used to determine the former costs, it is not clear whether this is also the case for the latter costs. However, as the duration of the threat T is rather small (a couple of hours to some days), so will be the influence of the discount rate. As such, although perhaps incorrect from a theoretical point of view, in practice one single discount rate **i** can be assigned by the user to deal with both costs.
- A monetary value α assigned to a unit of collective dose in order to express the implications of a decision strategy (costs and health effects) in one common unit.

Note that some time T_L may be 'lost' at the beginning of the decision process due to the collection of data related to the industrial factory, discussions on the intervention decision to be taken, etc. ERDOS allows to calculate the financial implications of this 'lost' time.

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[2] This will for instance be the case when these products have to be permanently mixed or heated in order to prevent them from coagulating, or when particular gasses are burned off deliberately to reduce explosion risks.

[3] Poisoning of catalysts, products sticking to reactor tubes, etc.

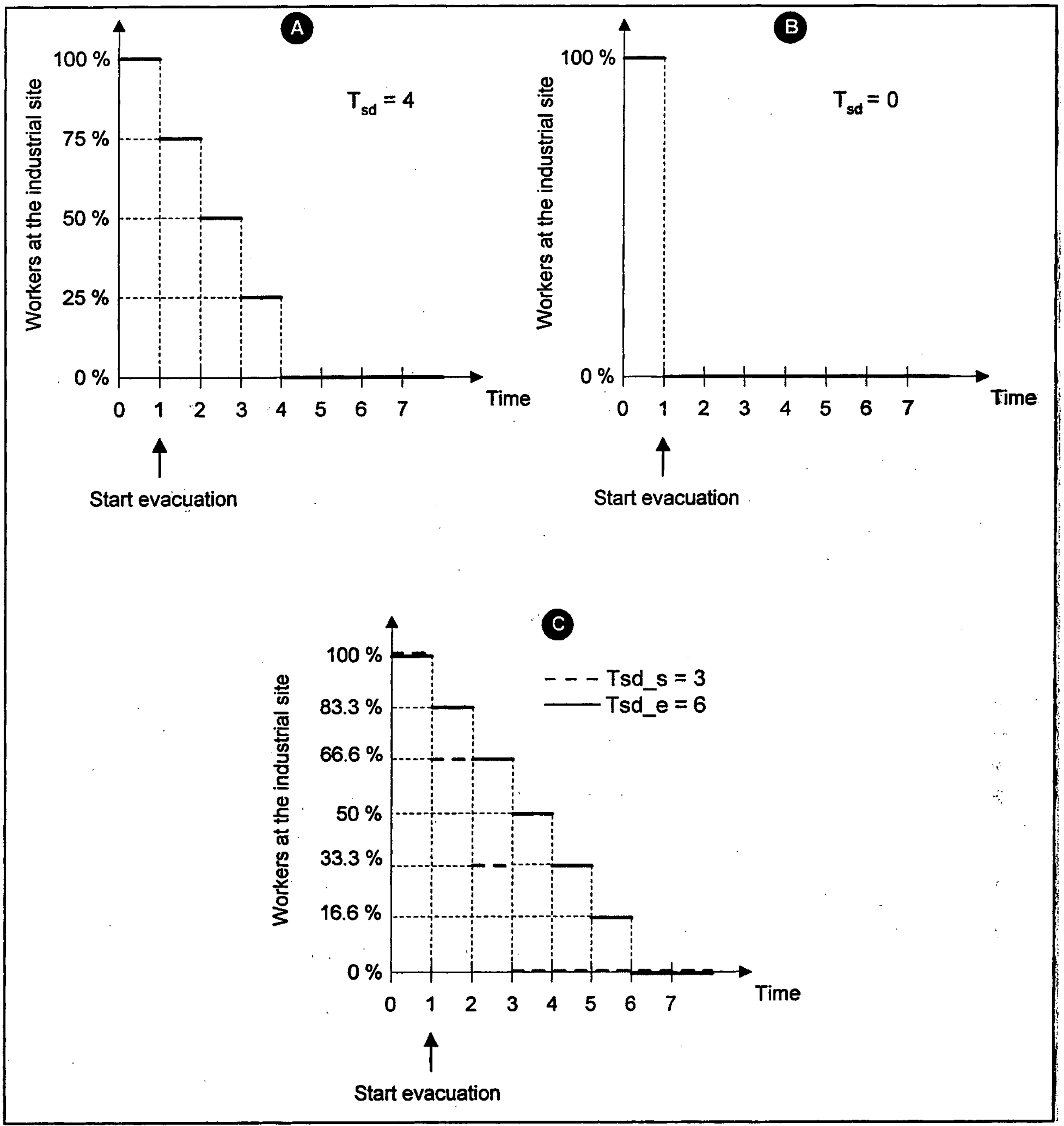

Figure 2. Percentage of the total number of workers present at the industrial factory as a function of time, when evacuation is started at the beginning of the second time period.

A schematic overview of the preventive evacuation decision problem and the information obtained from the several agents, is given in Figure 3.

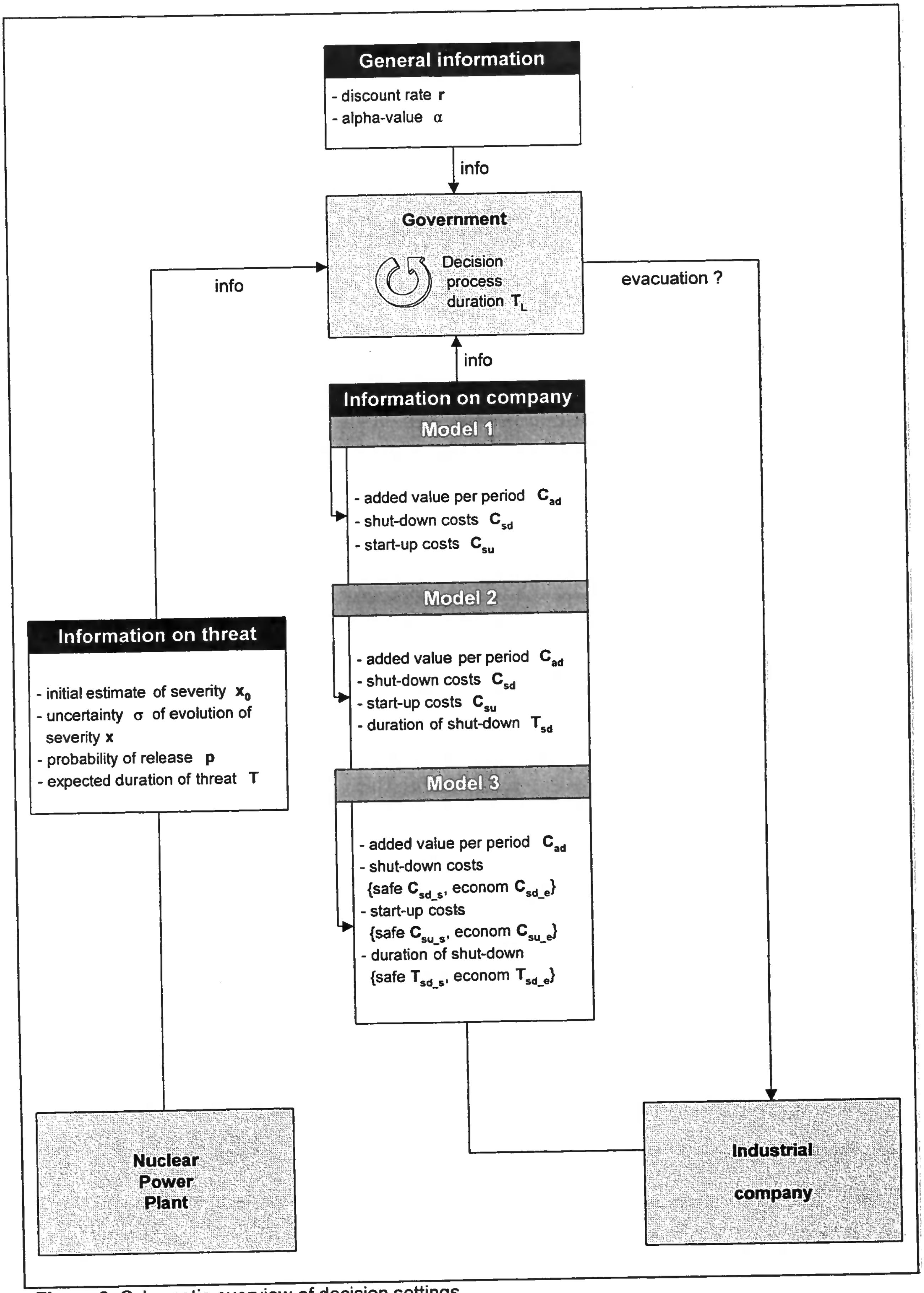

Figure 3. Schematic overview of decision settings

3 A decision model

3.1 Stochastic process

As mentioned in the previous section, the estimated severity of the release is only 'known' in case it would occur immediately at t_0, i.e. x_0. The severity as it will be estimated at a later point in time, however, is highly uncertain. Therefore, the evolution of the estimated severity over time is modelled by means of a geometric Brownian motion without drift

$$(2) \quad dx = \sigma x dz \quad ,$$

where
dx is the change in the estimated severity x in a time interval dt;
σ is the instantaneous variance rate;
dz is the increment of a Wiener process.

This stochastic process has the following characteristics [5, 7]:

- Markov process: the probability distribution for all future values of x only depends on the current value of x, and is unaffected by past values of x;
- Independent increments: the probability distribution for the change in x over any time interval is independent of any other nonoverlapping time interval;
- Percentage changes in x, i.e. dx/x, are normally distributed with a variance that increases linearly with time: the further one looks into the future, the larger will be the uncertainty.

By dividing the time-horizon of interest T into n equally spaced time periods of length Δt,[4] the geometric Brownian motion (2) can be approximated in discrete time by the binomial model

$$(3) \quad x_{t+1} = \begin{cases} u \cdot x_t & \text{in case of an upward jump (probability } q) \\ d \cdot x_t & \text{in case of a downward jump (probability } 1-q) \end{cases} ,$$

where
x_t is the estimated severity at time t;
x_{t+1} is the estimated severity at time t+1;
u is the impact factor of an upward jump ($u > 1$);
d is the impact factor of a downward jump ($d < 1$);
q is the <u>risk-neutral</u> probability [4, 7 ,8] of an upward jump in time period Δt.

The parameters u, d and q have to be chosen such that the statistical characteristics of the binomial model (3) when Δt becomes infinitesimally small, are those of the geometric Brownian motion (2). It has been shown elsewhere [4, 7] that this is the case for

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[4] The maximum number of time periods n supported by ERDOS is 500. In case the threat is expected to last for T = 24 hours, this would result in n = 500 time periods of length $\Delta t \approx 3$ minutes each.

(4) $u = e^{\sigma\sqrt{\Delta t}}$,

(5) $d = \frac{1}{u}$,

and

(6) $q = \frac{e^{r\Delta t} - d}{u - d}$.

Note that condition (5) is required in order to have a recombining tree in the sense that an equal number of up- and downward jumps returns the process to the same state, no matter in which order they occurred.

Figure 4 gives a graphical representation of the resulting binomial tree in case N=4 equally spaced points in the time interval of interest T are chosen. The process starts at time t=0 in state y=0. At each following point in time, the process can either branch up or down to arrive at the next state. Note that the number of possible states at time t equals (t+1).[5]

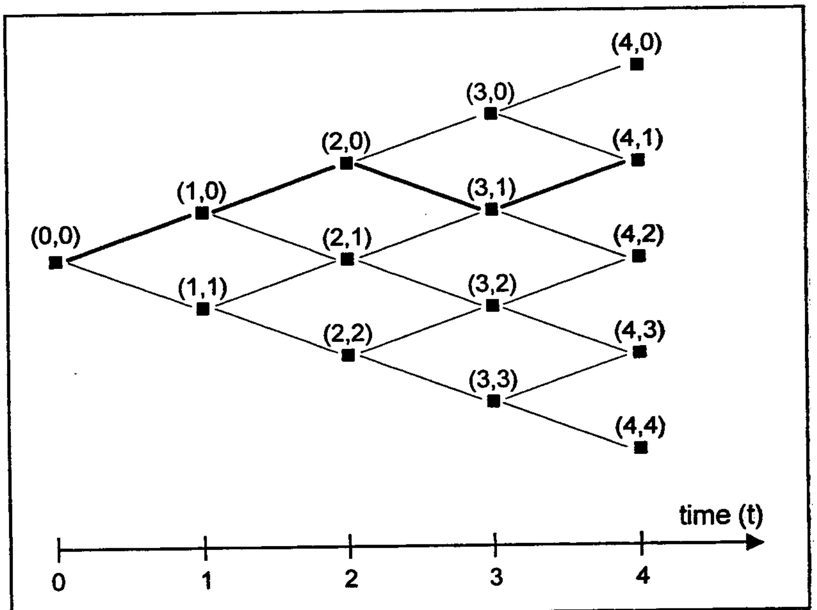

Figure 4. Binomial tree for N = 4 time periods. Co-ordinates (t, y) expressing the total number of downward jumps y at time t, and a sample path (uudu) are shown.

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[5] In case the tree was not recombining, the number of feasible states at time t would equal 2^t.

3.2 Optimal stopping

The preventive evacuation decision problem described in section 2 has some important similarities with typical optimal stopping problems. The governmental decision maker initially holds an American call option which gives him the right - but not the obligation - to take an irreversible decision, i.e. to evacuate the workers of the threatened industrial factory. At every point in time he has a binary choice: exercising his option (i.e. 'stopping the process') at a particular cost, i.e. the evacuation costs C(t), or waiting one more time period Δt (i.e. 'continuing the process') to observe the evolution of the severity of the expected release before deciding on the appropriate intervention. In the latter case, however, there is a probability p that the release occurs whilst he is waiting, resulting in the loss of the evacuation option[6] and hence, in the costs of health effects αx_t. The structure of this decision problem is graphically depicted in Figure 5.

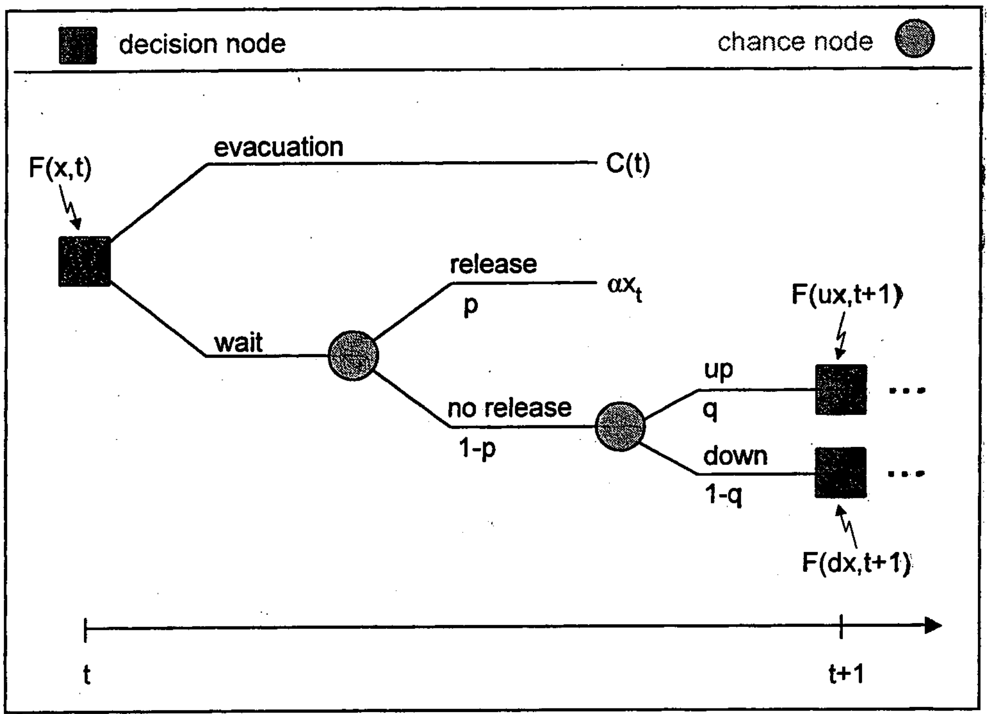

Figure 5. Problem faced by the decision maker at every point in time t.

This optimal stopping problem can be solved by means of a backward calculation procedure. Starting at the end of the time horizon, i.e. at time T, the optimal action is determined. This will provide the necessary information to solve the decision problem at the penultimate point in time, T-1. As such, by rolling *backward* (T → T-1 → ... → t → t-1 → ... → 0) through the tree, at every point in time that action can be chosen that leads to the smallest instantaneous and expected future costs. For instance at time t (cf. Fig. 5), we have

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[6] This phenomenon of loosing the option due to an uncontrollable event is very similar to what is referred upon in financial options literature as *default risk* in options traded over-the-counter [6].

$$(8) \quad F(x,t) = \min\left[C(t), p\alpha x_t + e^{-r\Delta t} \cdot \varepsilon\left[F(x+\Delta x, t+\Delta t)\right]\right],$$

where

$F(x, t)$	are the costs of the option[7] in case the estimated severity of the release at time t is given by x;
$C(t)$	are the costs of the evacuation decision at time t;
p	is the probability of the release taking place in a period of time Δt;
x_t	is the estimated severity at time t of the potential release;
α	is the monetary value of a unit of collective dose;
r	is the continuously compounded yearly discount rate;

and

$$(9) \quad \varepsilon\left[F(x+\Delta x, t+\Delta t)\right] = q \cdot F(ux, t+1) + (1-q) \cdot F(dx, t+1),$$

where

q	is the probability of an upward jump in a period of time Δt;
$F(\bullet, t+1)$	are the costs of the option in case the estimated severity of the release at time t+1 is given by $\bullet$.

At the end of this procedure, the optimal initial action can be determined. This action will satisfy Bellman's principle of optimality: it will result in the smallest immediate costs and expected costs at later stages of the decision process, assuming that subsequent actions will be taken optimally too, contingent on the state of nature that is revealed at that time. For an extensive discussion on these matters, we refer to [2, 5].

Finally, note that the costs of taking the evacuation decision at time t may consist of two terms. The first term represents the economic costs $C_{ec}(t)$ of the evacuation decision, whereas the second stands for the expected costs of the health effects $C_{he}(t)$, the evacuation decision notwithstanding. The latter only occur in case some time is required to execute the shut-down, i.e. in models 2 and 3.

The economic costs $C_{ec}(t)$ of the decision to evacuate at time t are given by

$$(10) \quad C_{ec}(t) = C_{sd} + \sum_{j=1}^{T-t} e^{-r \cdot j \cdot \Delta t} \cdot C_{ad} + e^{-r \cdot (T-t) \cdot \Delta t} \cdot C_{su},$$

where

C_{sd}	are the costs of shutting down the industrial factory;
C_{ad}	are the costs of the added value that is forgone during one time period Δt;
C_{su}	are the costs of restarting the industrial factory after a period of shut-down;
T	is the duration of the threat;
r	is the continuously compounded yearly discount rate.

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[7] F(x,t) refers to the *costs* associated to the 'evacuation option'. Traditionally, F(x,t) refers to the *value* of the option. This is due to our assumption that the decision maker seeks to minimise total expected costs, whereas in traditional investment literature, the objective of the decision maker consists in maximising expected net benefits.

Note that it is assumed in (10) that once the evacuation is initiated, the workers will remain evacuated until the end of the threat, i.e. until time T. This is in agreement with our previous assumption that the release - in case it occurs - will mainly consist of noble gasses (cf. footnote 1).

The expected costs of the health effects $C_{he}(t)$, notwithstanding the evacuation decision at time t are given by

$$(11) \quad C_{he}(t) = \alpha x_t \cdot \sum_{n=1}^{T_{sd}-1} \left[p(1-p)^{n-1} \cdot \frac{T_{sd}-n}{T_{sd}} \right],$$

where

α is the monetary value of one unit of collective dose;

x_t is the estimated severity of the release at time t;

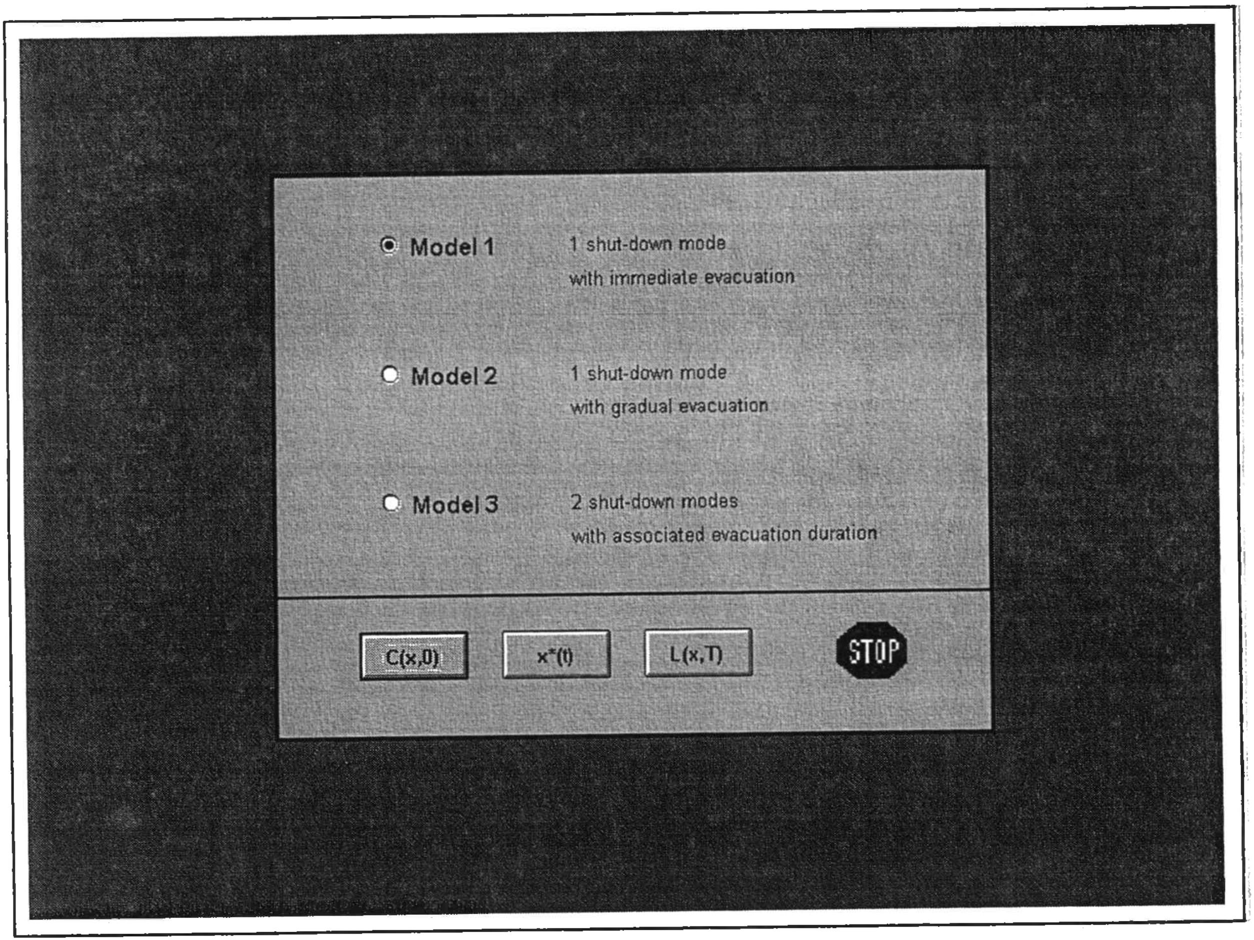
p is the probability of a release taking place in a time period Δt;

T_{sd} is the duration of the shut-down.

4 User guide

In the main menu (Fig. 6), the required complexity of the decision model is determined. The first and simplest model assumes that the industrial facility can be shut down instantaneously. Model 2, however, starts from the assumption that a particular time period is required in order to shut down the industrial production processes: some of the industrial workers will have to remain on the site until the shut-down is completed. Finally, the third and most complicated model takes into account the existence of two feasible modes of shutting down the industrial installations: either in a fast, but expensive way or in a slower, yet economic more efficient way.

Furthermore, the type of analysis that will be executed has to be determined. The user may first choose to calculate the expected costs of the optimal strategy as a function of the initially estimated severity of the potential release. Secondly, ERDOS can calculate the free boundary, giving the critical severity of the release as a function of time that will trigger immediate evacuation in case it is exceeded. Finally, the program can be used to calculate the financial implications of 'loosing' time during the initial stages of the decision process.



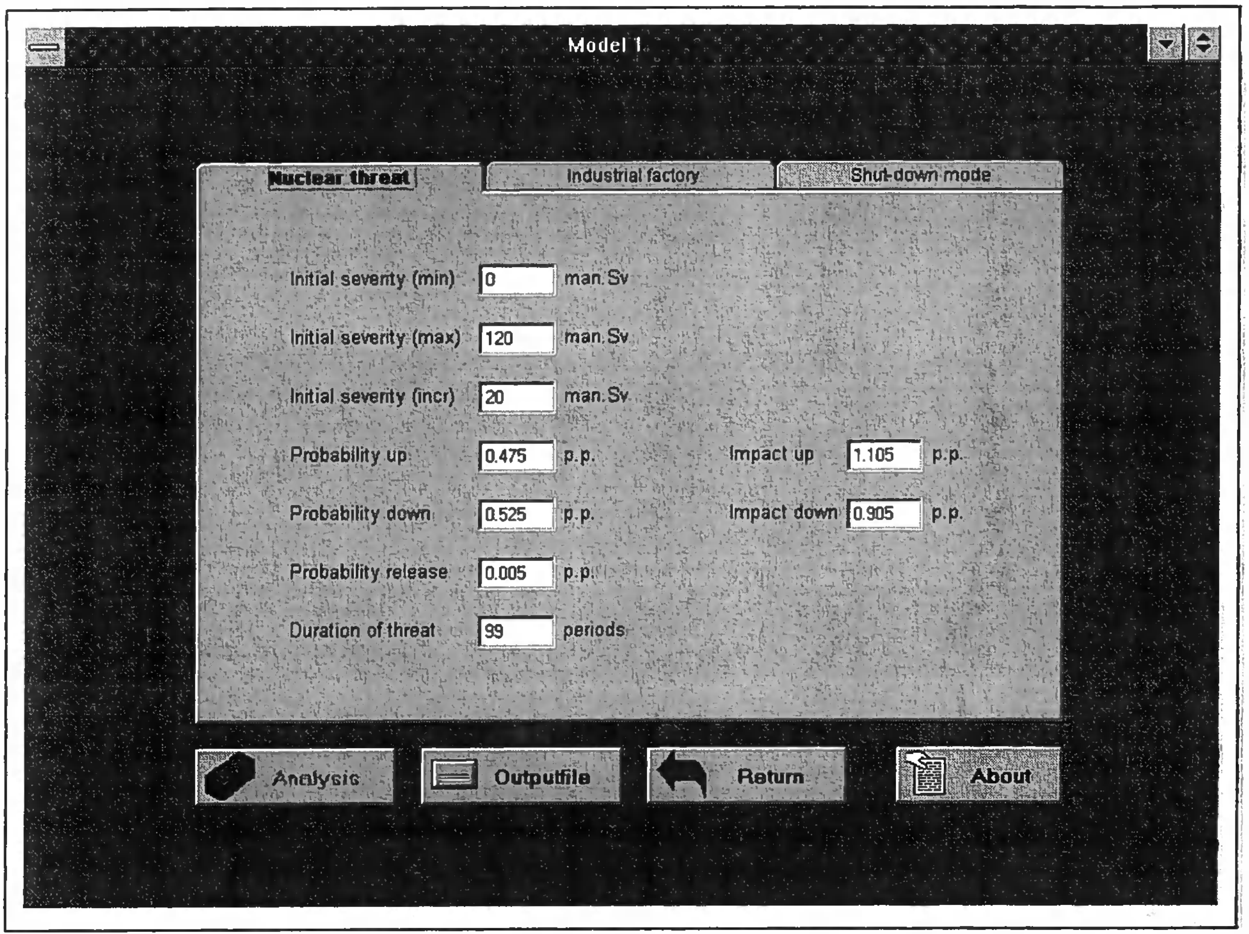
● Model 1 — 1 shut-down mode with immediate evacuation

○ Model 2 — 1 shut-down mode with gradual evacuation

○ Model 3 — 2 shut-down modes with associated evacuation duration

Figure 6. Main menu

Depending on the model and the analysis selected by the user a new screen (as the one shown in Figure 7) will pop up.



Initial severity (min) 0 man.Sv
Initial severity (max) 120 man.Sv
Initial severity (incr) 20 man.Sv
Probability up 0.475 p.p.
Impact up 1.105 p.p.
Probability down 0.525 p.p.
Impact down 0.905 p.p.
Probability release 0.005 p.p.
Duration of threat 99 periods

Figure 7. Example of subsequent menu (calculation of costs, model 1)

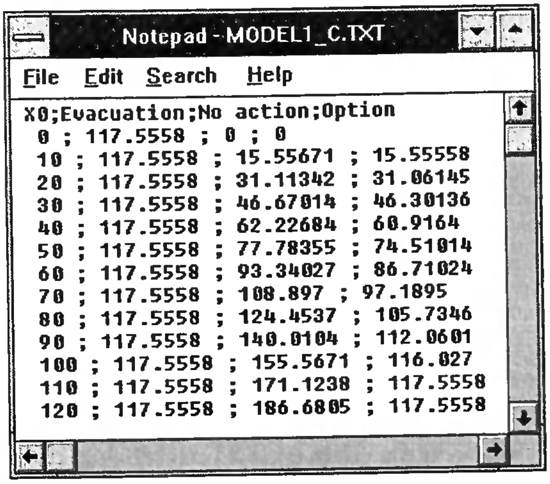
The procedure to be followed by the user in this stage of the analysis can be summarised as follows.

1. Fill in the appropriate values for each of the parameters.
   Appendix 1 gives an overview of the interpretation of each of the inputparameters, prevailing in the different models. The user can switch (with a click of the mouse) between the three tab-pages "Nuclear threat", "Industrial factory" and "Shut-down mode".
2. Select a filename for storage of the results by clicking on the button "Outputfile".
3. Start the analysis by clicking on the button "Analysis", which is now clickable.
4. A message will indicate that the analysis has been completed successfully.

The results stored in the outputfile (*.txt) can be imported in MSExcel for further analysis. An overview and interpretation of the thus obtained results is provided in the next section.

As long as the analysis has not been initiated, the user can go back to the main menu by clicking on the button "Return". The button "About" gives some general information on the software (version, date of release, etc.).

5 Output



```
X0;Evacuation;No action;Option
 0 ; 117.5558 ; 0 ; 0
 10 ; 117.5558 ; 15.55671 ; 15.55558
 20 ; 117.5558 ; 31.11342 ; 31.06145
 30 ; 117.5558 ; 46.67014 ; 46.30136
 40 ; 117.5558 ; 62.22684 ; 60.9164
 50 ; 117.5558 ; 77.78355 ; 74.51014
 60 ; 117.5558 ; 93.34027 ; 86.71024
 70 ; 117.5558 ; 108.897 ; 97.1895
 80 ; 117.5558 ; 124.4537 ; 105.7346
 90 ; 117.5558 ; 140.0104 ; 112.0601
 100 ; 117.5558 ; 155.5671 ; 116.027
 110 ; 117.5558 ; 171.1238 ; 117.5558
 120 ; 117.5558 ; 186.6805 ; 117.5558
```

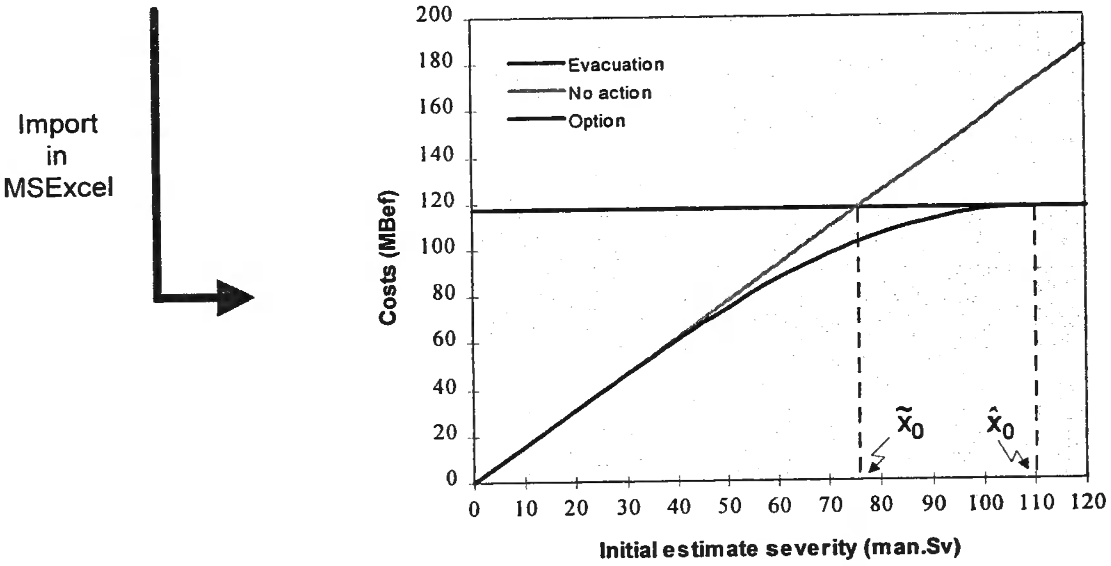
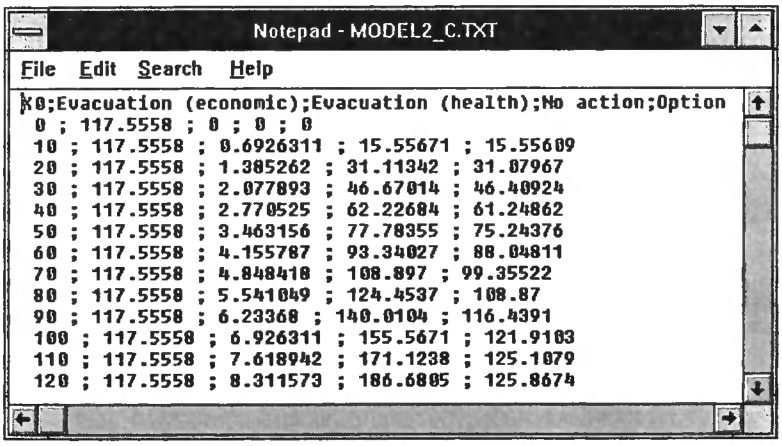


Figure 8. Output of calculating costs in model 1.

Interpretation

A decision maker who ignores option characteristics and considers the evacuation decision problem as a 'now or never' decision, will decide to evacuate the workers of the industrial factory immediately at t_0, the time of the initial alarm, in case the estimated severity of the potential release exceeds $\tilde{x}_0$. However, if option characteristics are taken into account, evacuation will only be decided upon in case the initially estimated severity exceeds $\hat{x}_0$. As such, wrong decisions may result for values of the initial estimate of the severity x in the interval $\left[\tilde{x}_0, \hat{x}_0\right]$.



```
x0;Evacuation (economic);Evacuation (health);No action;Option
 0 ; 117.5558 ; 0 ; 0 ; 0
 10 ; 117.5558 ; 0.6926311 ; 15.55671 ; 15.55609
 20 ; 117.5558 ; 1.385262 ; 31.11342 ; 31.07967
 30 ; 117.5558 ; 2.077893 ; 46.67014 ; 46.40924
 40 ; 117.5558 ; 2.770525 ; 62.22684 ; 61.24862
 50 ; 117.5558 ; 3.463156 ; 77.78355 ; 75.24376
 60 ; 117.5558 ; 4.155787 ; 93.34027 ; 88.04811
 70 ; 117.5558 ; 4.848418 ; 108.897 ; 99.35522
 80 ; 117.5558 ; 5.541049 ; 124.4537 ; 108.87
 90 ; 117.5558 ; 6.23368 ; 140.0104 ; 116.4391
 100 ; 117.5558 ; 6.926311 ; 155.5671 ; 121.9103
 110 ; 117.5558 ; 7.618942 ; 171.1238 ; 125.1079
 120 ; 117.5558 ; 8.311573 ; 186.6805 ; 125.8674
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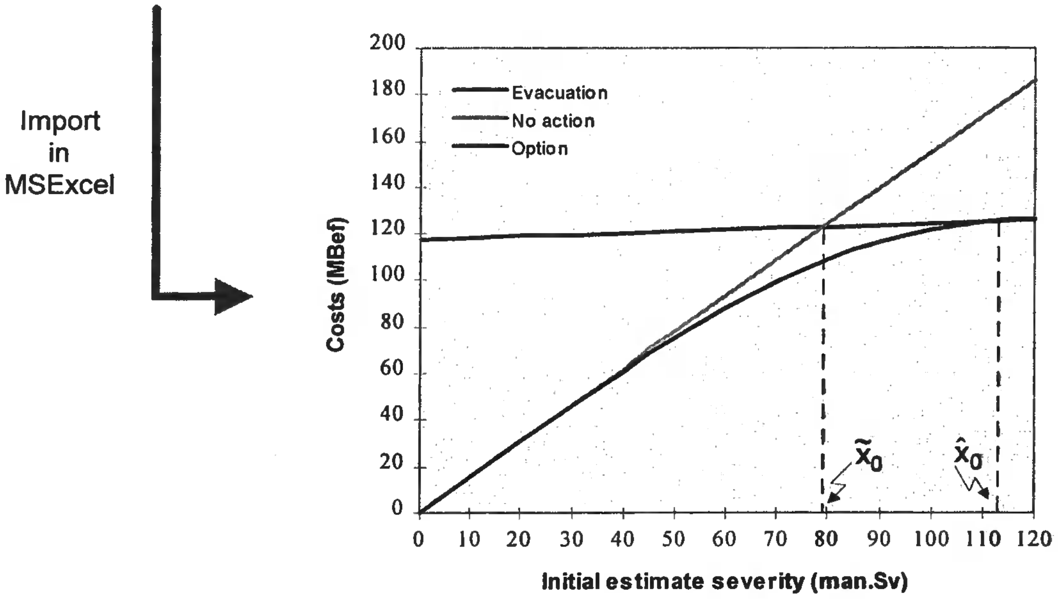
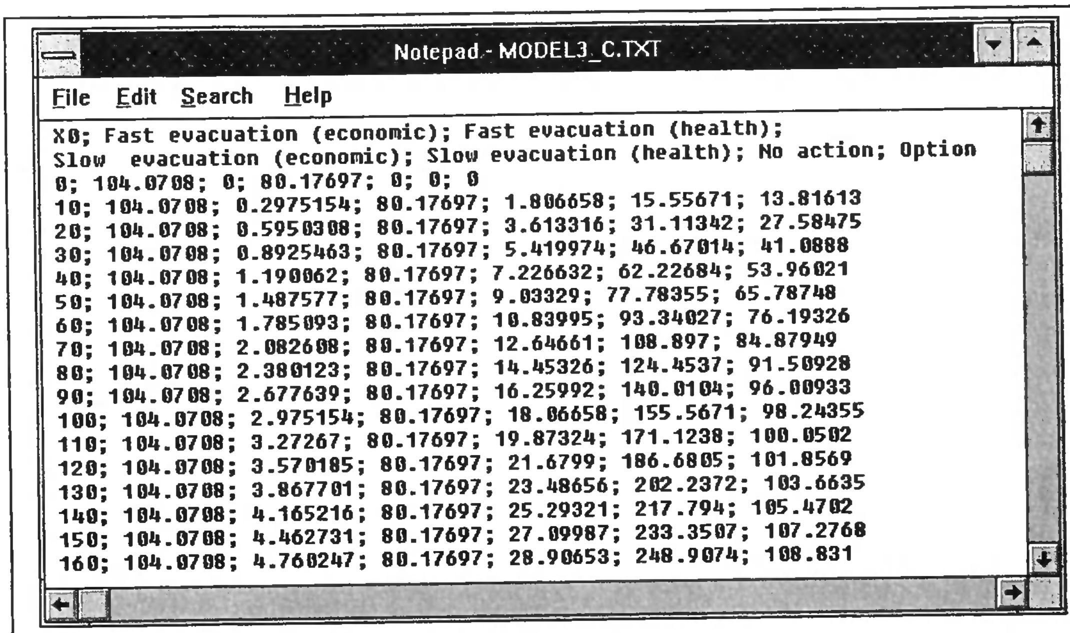


Figure 9. Output of calculating costs in model 2.

Interpretation

Again, a decision maker who ignores option characteristics and considers the evacuation decision problem as a 'now or never' decision, will decide to evacuate the workers of the industrial factory immediately at t_0, the time of the initial alarm, in case the expected severity of the potential release exceeds $\tilde{x}_0$. However, if option characteristics are taken into account, evacuation will only be decided upon in case the initially estimated severity exceeds $\hat{x}_0$. As such, wrong decisions may result for values of the initial estimate of the severity x in the interval $\left[\tilde{x}_0, \hat{x}_0\right]$.

Note that the costs of the evacuation decision are no longer constant (cf. Fig. 8), but an increasing function of the initial estimate of the severity x_0. It is assumed in model 2 that some time is required to execute the evacuation decision. As such, the expected costs of the health effects notwithstanding the evacuation decision must be taken into account: these costs are an increasing function of the severity of the potential release (cf. equation (11)).



```
X0; Fast evacuation (economic); Fast evacuation (health);
Slow  evacuation (economic); Slow evacuation (health); No action; Option
0; 104.0708; 0; 80.17697; 0; 0; 0
10; 104.0708; 0.2975154; 80.17697; 1.806658; 15.55671; 13.81613
20; 104.0708; 0.5950308; 80.17697; 3.613316; 31.11342; 27.58475
30; 104.0708; 0.8925463; 80.17697; 5.419974; 46.67014; 41.0888
40; 104.0708; 1.190062; 80.17697; 7.226632; 62.22684; 53.96021
50; 104.0708; 1.487577; 80.17697; 9.03329; 77.78355; 65.78748
60; 104.0708; 1.785093; 80.17697; 10.83995; 93.34027; 76.19326
70; 104.0708; 2.082608; 80.17697; 12.64661; 108.897; 84.87949
80; 104.0708; 2.380123; 80.17697; 14.45326; 124.4537; 91.50928
90; 104.0708; 2.677639; 80.17697; 16.25992; 140.0104; 96.00933
100; 104.0708; 2.975154; 80.17697; 18.06658; 155.5671; 98.24355
110; 104.0708; 3.27267; 80.17697; 19.87324; 171.1238; 100.0502
120; 104.0708; 3.570185; 80.17697; 21.6799; 186.6805; 101.8569
130; 104.0708; 3.867701; 80.17697; 23.48656; 202.2372; 103.6635
140; 104.0708; 4.165216; 80.17697; 25.29321; 217.794; 105.4702
150; 104.0708; 4.462731; 80.17697; 27.09987; 233.3507; 107.2768
160; 104.0708; 4.760247; 80.17697; 28.90653; 248.9074; 108.831
```

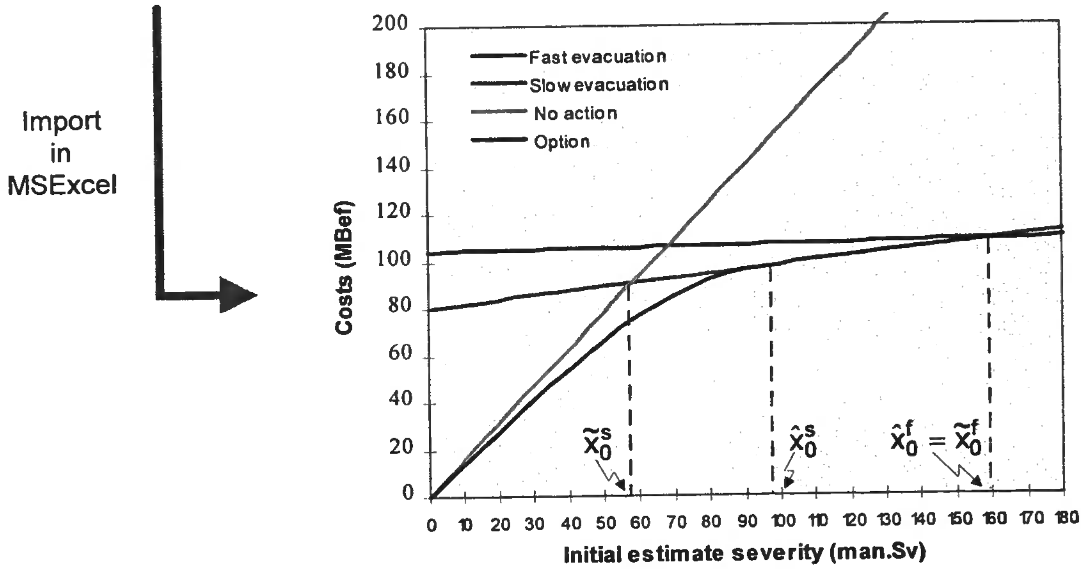
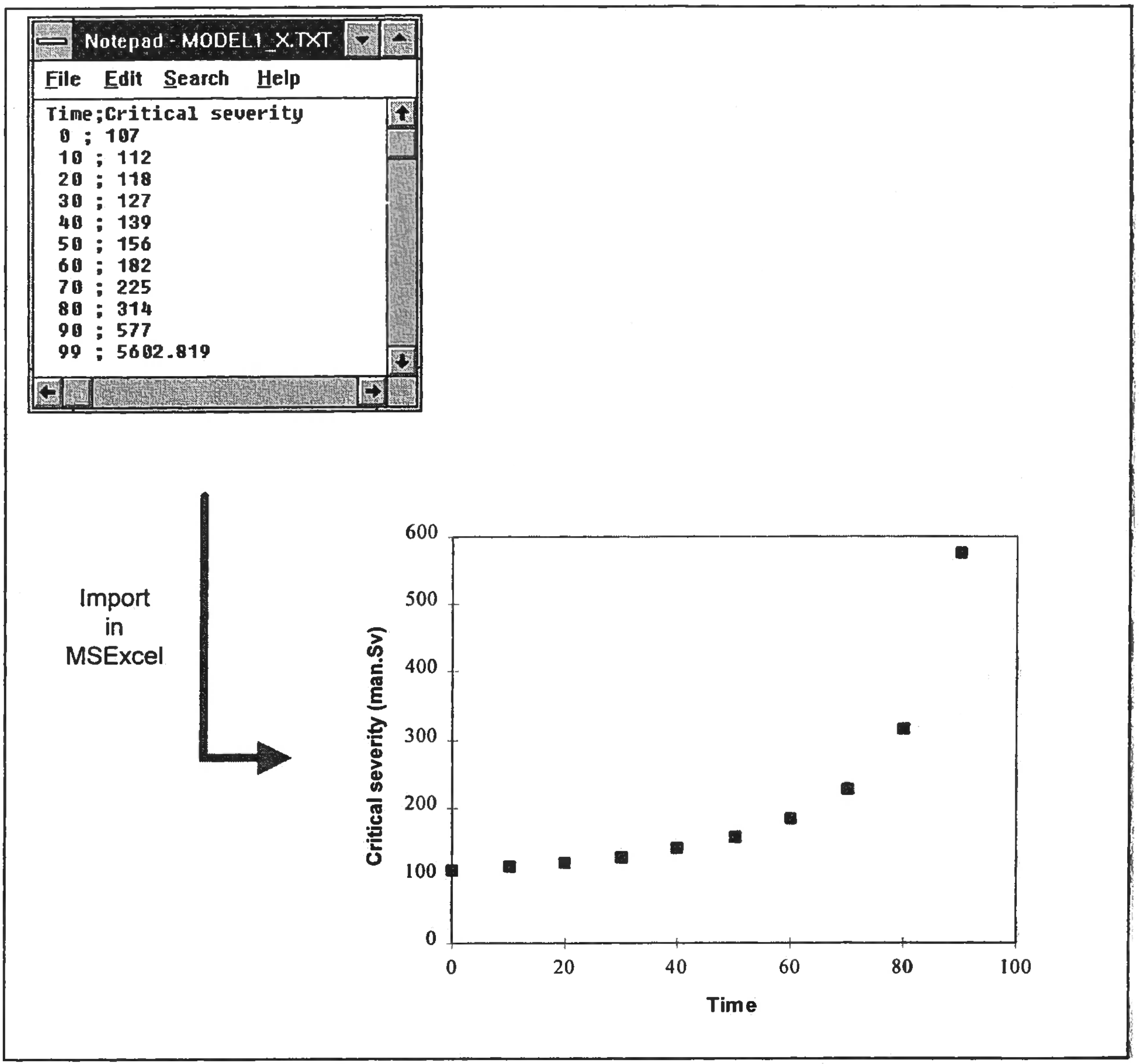


Figure 10. Output of calculating costs in model 3.

Interpretation

A decision maker who ignores option characteristics and considers the evacuation decision problem as a 'now or never' decision, will decide to shut down the industrial factory slowly or fastly, in case the estimated severity of the potential release exceeds $\tilde{x}_0^s$ or $\tilde{x}_0^f$ respectively. However, if option characteristics are taken into account, a slow or fast shut-down will only be decided upon in case the initially estimated severity exceeds $\hat{x}_0^s$ or $\hat{x}_0^f$ respectively. As such, wrong decisions may result for values of the initial estimate of the severity x in the interval $\left[\tilde{x}_0^s, \hat{x}_0^s\right]$. The critical values $\tilde{x}_0^f$ and $\hat{x}_0^f$, however, coincide.



```
Time;Critical severity
 0 ; 107
 10 ; 112
 20 ; 118
 30 ; 127
 40 ; 139
 50 ; 156
 60 ; 182
 70 ; 225
 80 ; 314
 90 ; 577
 99 ; 5602.819
```

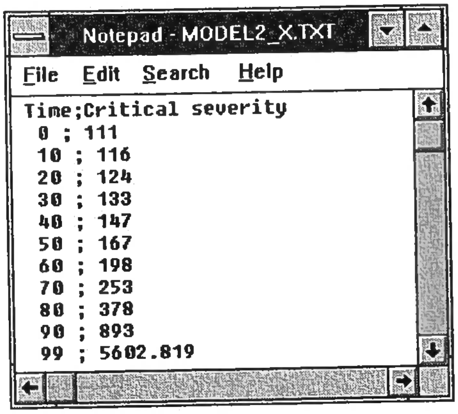
Figure 11. Output of calculating trigger levels in model 1.

Interpretation

Figure 11 presents the free boundary, i.e. the critical level of the severity as a function of time that will trigger immediate evacuation in case it is exceeded. As long as the estimated severity at time t, x(t), is below the trigger level x*(t), the decision maker will decide to wait for further information on the evolution of the alarm situation. However, as soon as the estimated severity x(t) jumps above this trigger level x*(t), evacuation is initiated.

This free boundary is an exponentially increasing function of time: the smaller the remaining duration T-t of the threat, the smaller will be the probability of a release effectively taking place. Therefore, a more severe release has to be anticipated in order to still 'trigger' the evacuation decision.

Note that the trigger level at time t_0 equals $\hat{x}_0$ in Figure 8.



```
Time;Critical severity
 0 ; 111
 10 ; 116
 20 ; 124
 30 ; 133
 40 ; 147
 50 ; 167
 60 ; 198
 70 ; 253
 80 ; 378
 90 ; 893
 99 ; 5602.819
```

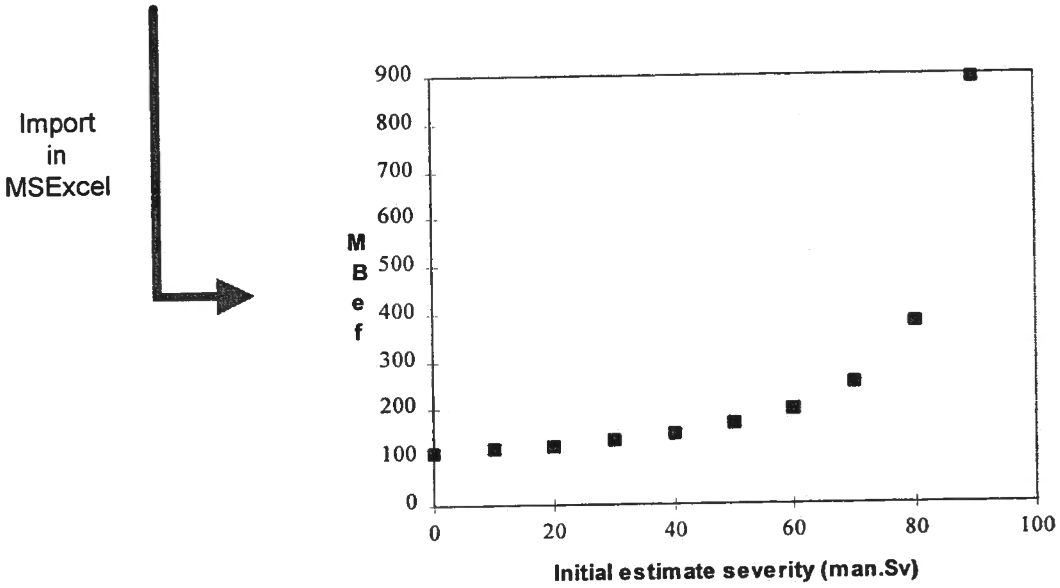


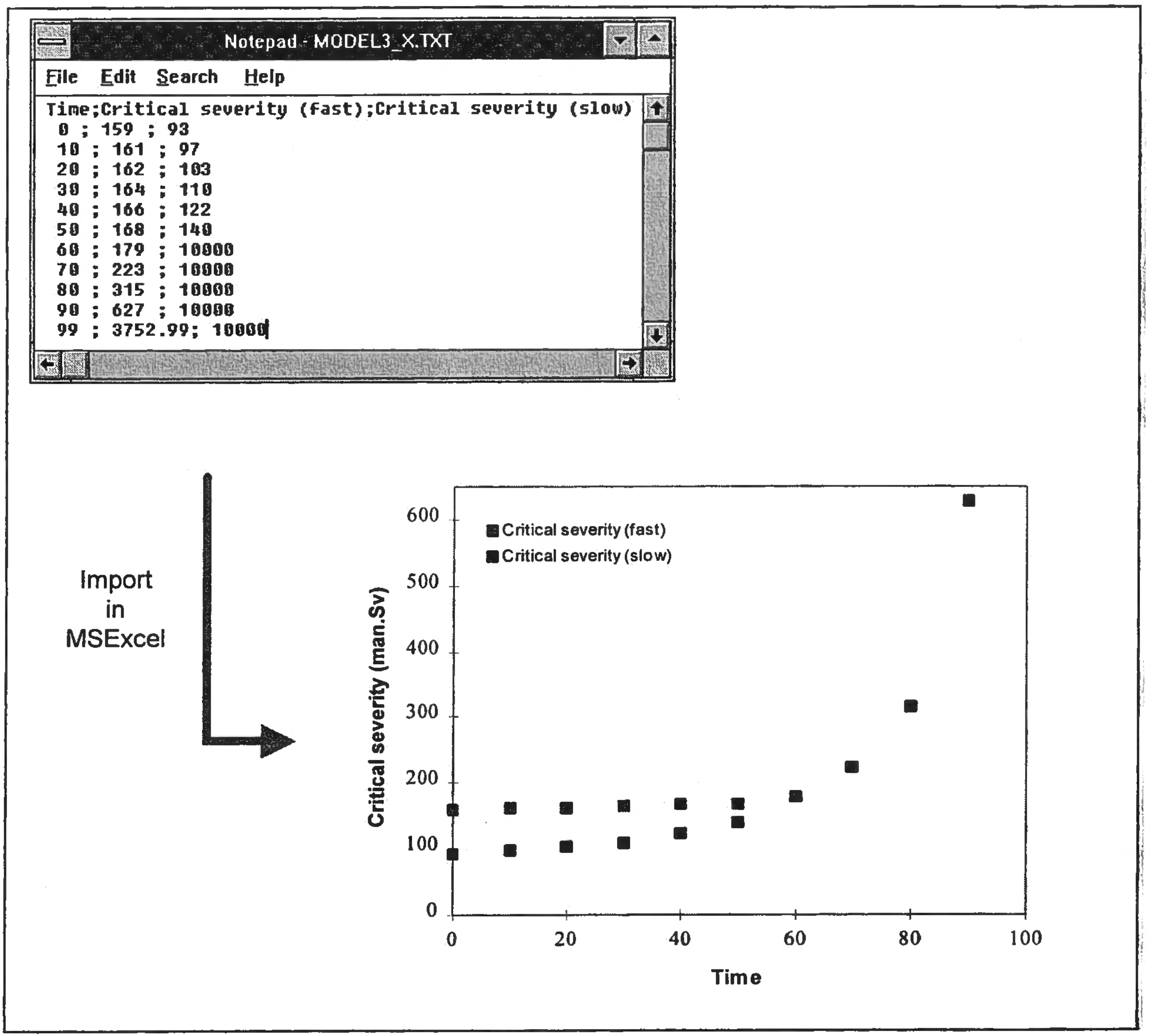
Figure 12. Output of calculating trigger levels in model 2.

Interpretation

Figure 12 presents the free boundary, i.e. the critical level of the expected severity as a function of time that will trigger immediate evacuation in case it is exceeded. As long as the estimated severity at time t, x(t), is below the trigger level x*(t), the decision maker will decide to wait for further information on the evolution of the alarm situation. However, as soon as this estimate x(t) jumps above x*(t), evacuation is initiated.

This free boundary is again an exponentially increasing function of time: the smaller the remaining duration T-t of the threat, the smaller will be the probability that a release will still effectively take place. Therefore, a more severe release has to be expected in order to 'trigger' the decision to evacuate the industrial factory.

Note that the trigger level at time t_0 equals $\hat{x}_0$ in Figure 9.



```
Time;Critical severity (fast);Critical severity (slow)
 0 ; 159 ; 93
 10 ; 161 ; 97
 20 ; 162 ; 103
 30 ; 164 ; 110
 40 ; 166 ; 122
 50 ; 168 ; 140
 60 ; 179 ; 10000
 70 ; 223 ; 10000
 80 ; 315 ; 10000
 90 ; 627 ; 10000
 99 ; 3752.99; 10000
```

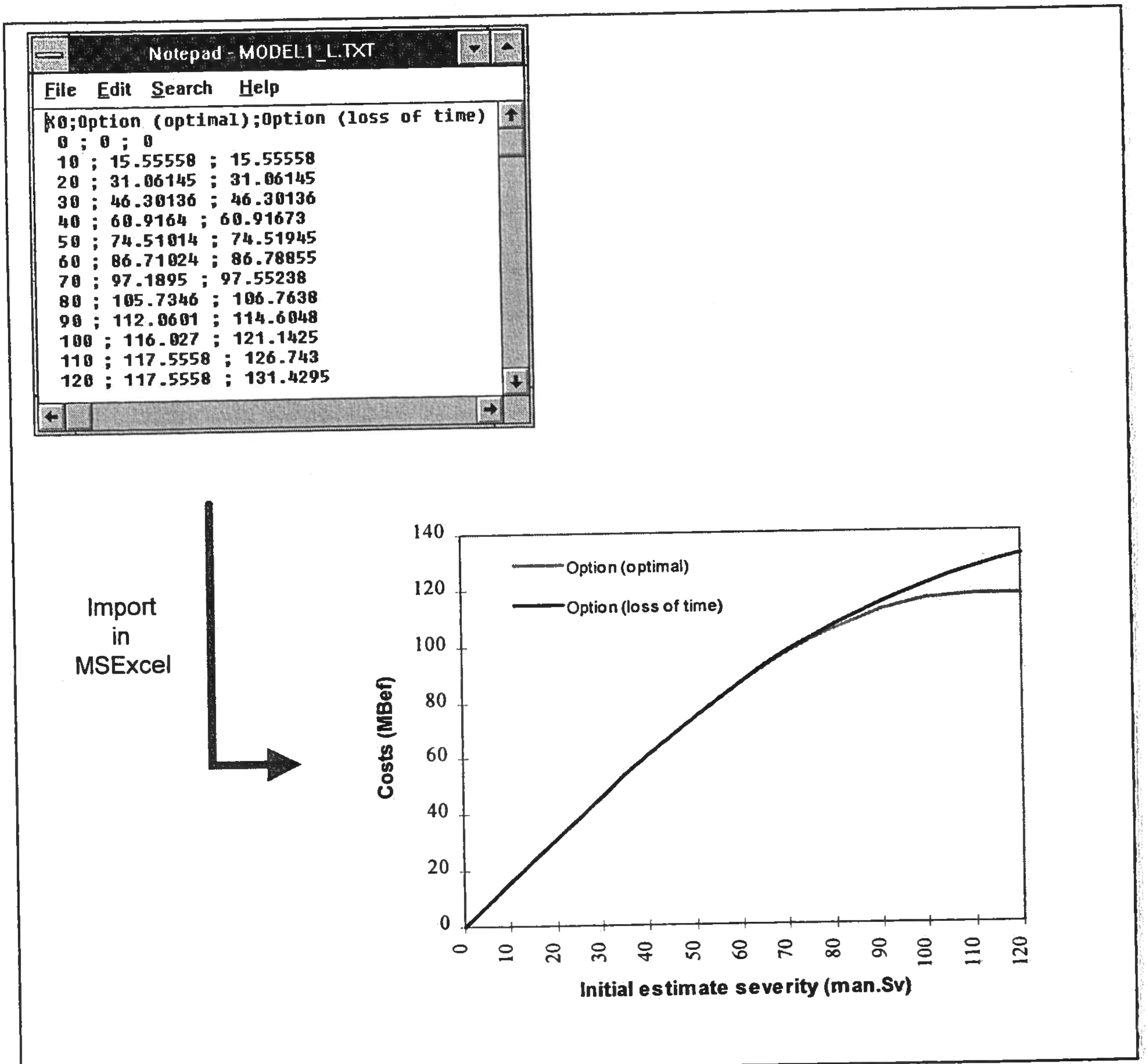
Figure 13. Output of calculating trigger levels in model 3.

Interpretation

Figure 13 presents the free boundary for slow (fast) evacuation, i.e. the critical level of the estimated severity as a function of time that will trigger immediate slow (fast) evacuation in case it is exceeded.

Note that the free boundary for fast evacuation is again an exponentially increasing function of the time. The free boundary for slow evacuation, however, initially increases exponentially, but stops when it meets the boundary for fast evacuation. From that point in time on, a slow shut-down is dominated by a fast shut-down, and as such will no longer be decided upon.

Note that the trigger level for slow and fast evacuation at time t_0 respectively equals $\hat{x}_0^s$ and $\hat{x}_0^f$ in Figure 10.



```
X0;Option (optimal);Option (loss of time)
 0 ; 0 ; 0
 10 ; 15.55558 ; 15.55558
 20 ; 31.06145 ; 31.06145
 30 ; 46.30136 ; 46.30136
 40 ; 60.9164 ; 60.91673
 50 ; 74.51014 ; 74.51945
 60 ; 86.71024 ; 86.78855
 70 ; 97.1895 ; 97.55238
 80 ; 105.7346 ; 106.7638
 90 ; 112.0601 ; 114.6048
 100 ; 116.027 ; 121.1425
 110 ; 117.5558 ; 126.743
 120 ; 117.5558 ; 131.4295
```

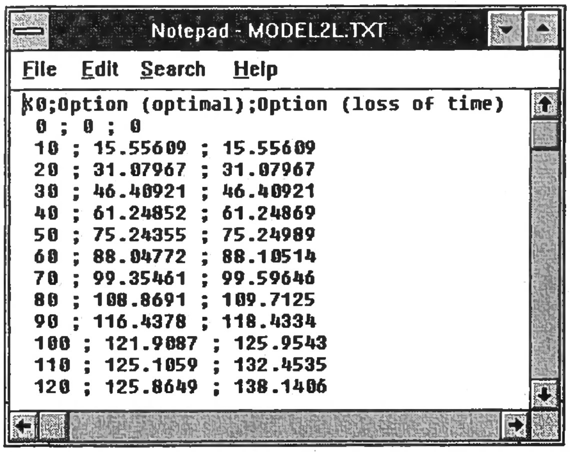
Figure 14. Output of calculating financial implications of 'loosing' time in model 1.

Interpretation

Figure 14 shows the expected costs of the optimal strategy in case no time is lost, and in case some time (12 time periods) is lost during the initial stages of the decision process. As such, the difference between both curves represents the financial losses due to this 'loss' of time.

For rather small values of the estimated severity of the release at t_0, these losses are negligibly small. However, for larger values of this estimated severity, these losses may become substantial.

Note that the green curve coincides with the option curve in Figure 8.



```
K0;Option (optimal);Option (loss of time)
 0 ; 0 ; 0
 10 ; 15.55609 ; 15.55609
 20 ; 31.07967 ; 31.07967
 30 ; 46.40921 ; 46.40921
 40 ; 61.24852 ; 61.24869
 50 ; 75.24355 ; 75.24989
 60 ; 88.04772 ; 88.10514
 70 ; 99.35461 ; 99.59646
 80 ; 108.8691 ; 109.7125
 90 ; 116.4378 ; 118.4334
 100 ; 121.9087 ; 125.9543
 110 ; 125.1059 ; 132.4535
 120 ; 125.8649 ; 138.1406
```

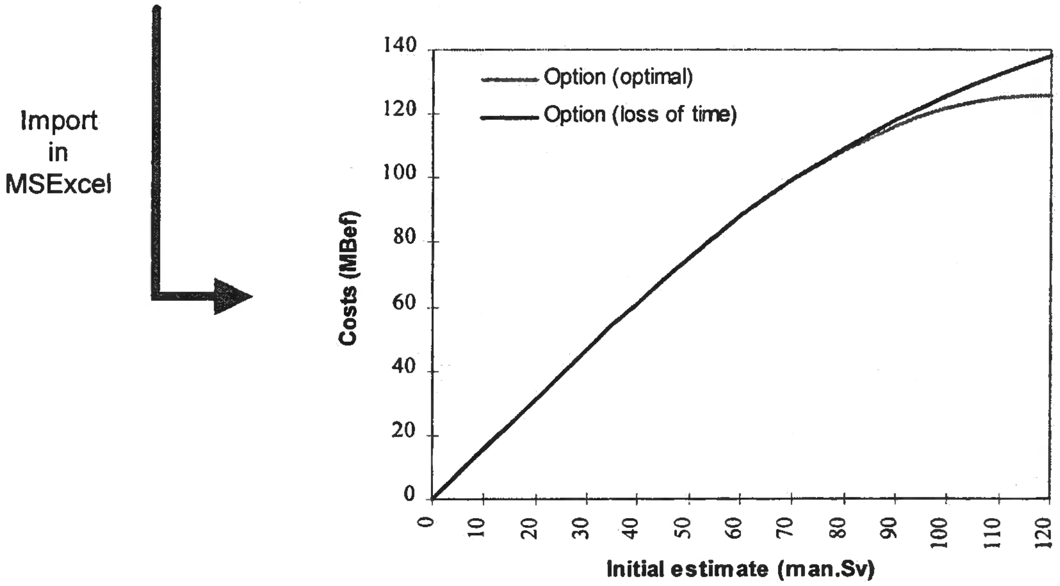


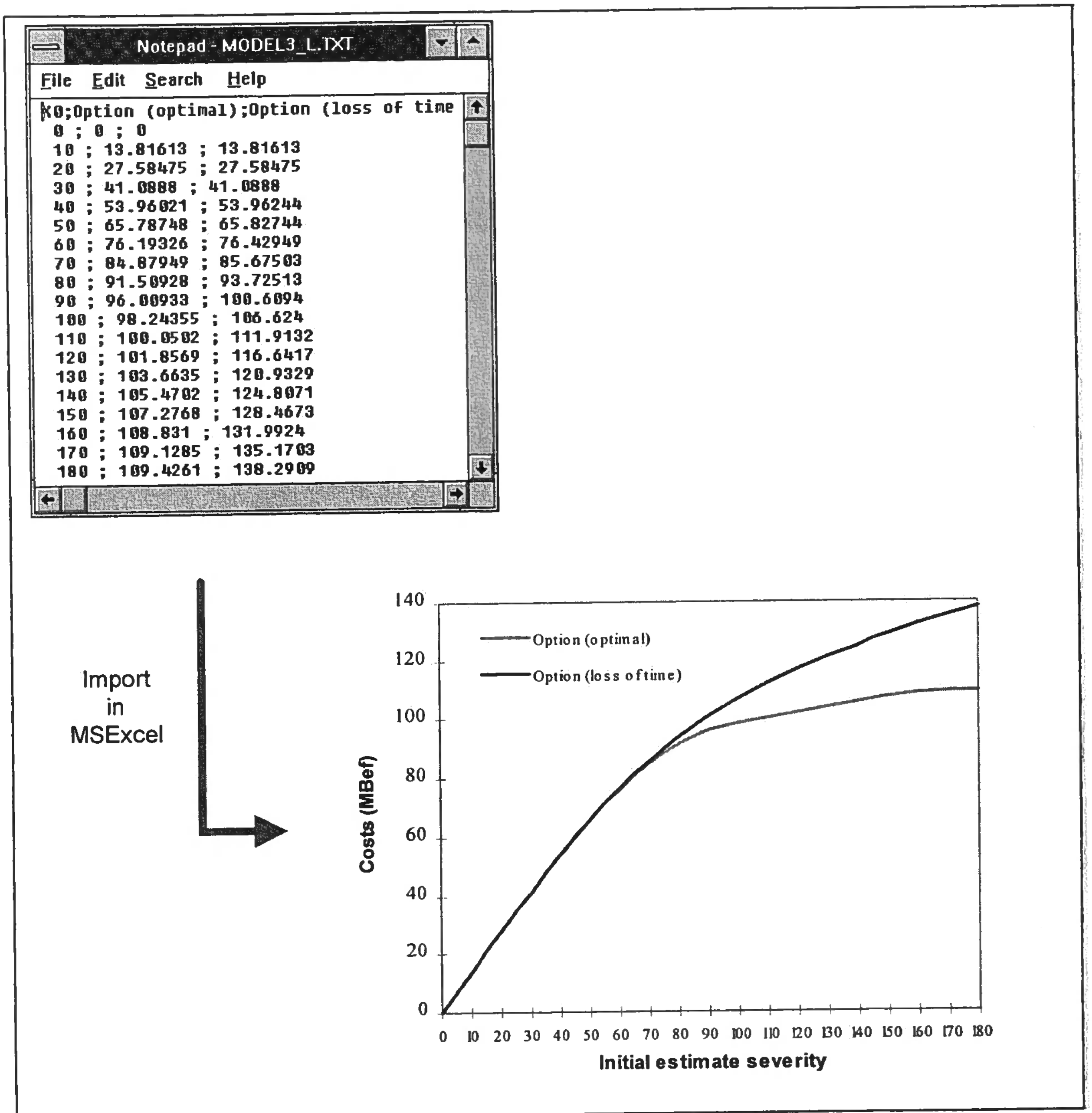
Figure 15. Output of calculating costs of 'loosing' time in model 2.

Interpretation

Figure 15 again shows the expected costs of the optimal strategy in case no time is lost, and in case some time (12 time periods) is lost during the initial stages of the decision process. As such, the difference between both curves again represents the financial losses due to this 'loss' of time.

For rather small values of the estimated severity of the release at t_0, these losses are negligibly small. However, for larger values of this estimated severity, these losses may become substantial.

Note that the green curve coincides with the option curve in Figure 9.



```
X0;Option (optimal);Option (loss of time
 0 ; 0 ; 0
 10 ; 13.81613 ; 13.81613
 20 ; 27.58475 ; 27.58475
 30 ; 41.0888 ; 41.0888
 40 ; 53.96021 ; 53.96244
 50 ; 65.78748 ; 65.82744
 60 ; 76.19326 ; 76.42949
 70 ; 84.87949 ; 85.67503
 80 ; 91.50928 ; 93.72513
 90 ; 96.00933 ; 100.6094
 100 ; 98.24355 ; 106.624
 110 ; 100.0502 ; 111.9132
 120 ; 101.8569 ; 116.6417
 130 ; 103.6635 ; 120.9329
 140 ; 105.4702 ; 124.8071
 150 ; 107.2768 ; 128.4673
 160 ; 108.831 ; 131.9924
 170 ; 109.1285 ; 135.1703
 180 ; 109.4261 ; 138.2909
```

Figure 16. Output of calculating costs of 'loosing' time in model 3.

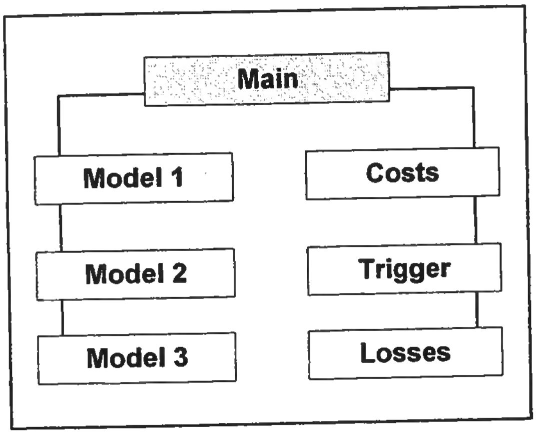
Interpretation

Figure 16 shows the expected costs of the optimal strategy in case no time is lost, and in case some time (12 time periods) is lost at the initial stages of the decision process. As such, the difference between both curves again represents the financial losses due to this 'loss' of time.

For rather small values of the estimated severity of the release at t_0, these losses are negligibly small. However, for larger values of the estimated severity, these losses may become substantial.

Note that the green curve coincides with the option curve in Figure 10.

6 Technical guide



Sub cmdCalcCosts
Sub cmdCalcCriticalSeverity
Sub cmdCalcLosses

The form *frmMainMenu* determines the complexity of the model (model 1, model 2 or model 3) that will be used for the analysis. Furthermore, the type of analysis to be performed (calculation of costs, trigger levels or losses due to the 'loss' of time) is settled. The form contains three command buttons, respectively initiating the procedures *cmdCalcCosts*, *cmdCalcCriticalSeverity* and *cmdCalcLosses*. In the following, these procedures will be discussed into detail.

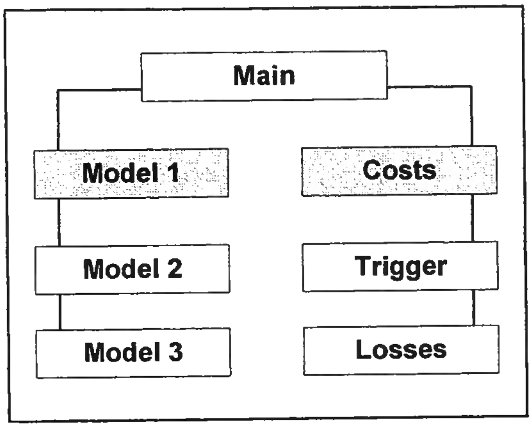
6.1 Sub cmdCalcCosts

The procedure *cmdCalcCosts* calculates as a function of the initially expected severity of the potential release:

- the costs of evacuating immediately;
- the expected costs of taking no action at all;
- the expected costs of the optimal strategy, i.e. the costs of the optimal initial action and the expected costs of subsequent actions, knowing that these later decisions will be taken optimally as well, contingent on the state of nature that is revealed at that time.

The procedure *cmdCalcCosts* unloads the form *frmMainMenu*. Afterwards *frmmodel1_C*, *frmmodel2_C* or *frmmodel3_C* is loaded depending on the model that is selected to be used in the main menu.

6.1.1 frmmodel1_C



Sub cmdModel1_Costs
Sub cmdOutputFile
Sub cmdReturn
Sub cmdAbout

The form *frmmodel1_C* makes use of the procedures *cmdModel1_Costs*, *cmdOutputFile*, *cmdReturn* and *cmdAbout*.

Sub cmdModel1_Costs

The procedure *cmdModel1_Costs* proceeds as follows:

- Initialising the modelparameters.
- Opening the outputfile that has previously been determined by the user.
- Determining the costs of evacuation at point in time.
  These evacuation costs consist of three components:
  - the costs C_{sd} of shutting down the installations;
  - the costs C_{ad} of the lost added value during the period of shut-down;
  - the start-up costs C_{su} at the end of the alarm situation.
- Determining the costs that are dependent on the evolution of the estimated severity of the potential release.
  - Determining the evolution of the estimated severity of the potential release as a function of time in a recombining binomial lattice (forward calculation).
  - Determining at every point in time, the costs of taking no action (backward calculation).
    These costs consist of two parts: the monetary costs of the health effects in case a release would take place in the next time period on the one hand, and the (discounted) costs that would potentially result in later time periods in case a release does not take place in the next time period, on the other hand.
  - Determining at every point in time, the costs of the optimal action (backward calculation).
    The optimal action and its associated costs, is determined by selecting the action (evacuation *vs* no action) that leads to the lowest expected costs.
  - Determining the costs of never evacuating the industrial factory.
- Writing the results to the outputfile.
- Ending the analysis.

Figure 17 presents the flowchart for this procedure.

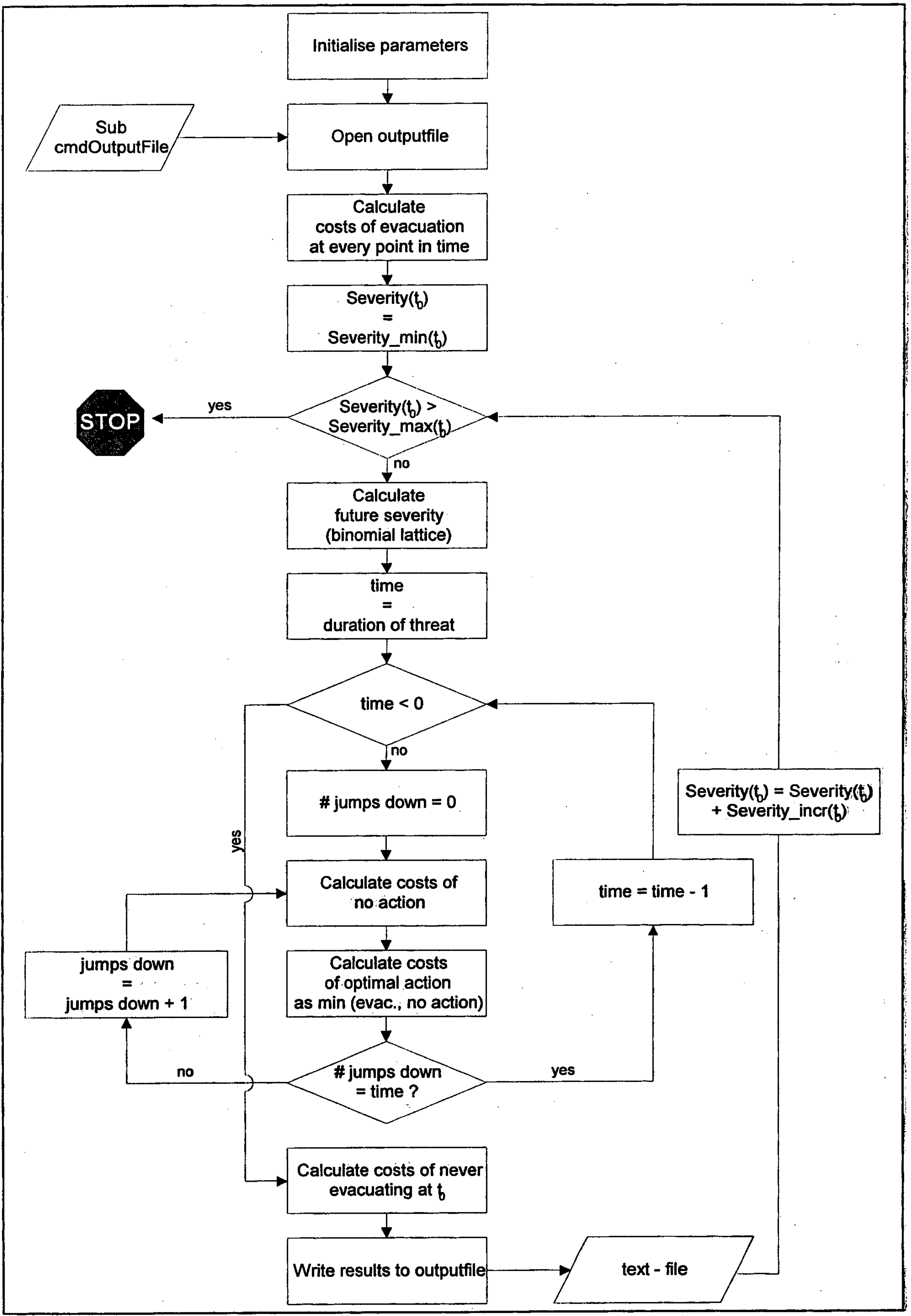


Figure 17. Flowchart for the procedure *cmdModel1_Costs*

Sub cmdOutputFile

The procedure *cmdOutputFile* loads a CommonDialog box, enabling to specify the name of the outputfile for storage of the results that will be obtained during the subsequent analysis. The results are stored in a text file (*.txt), where data is separated by semicolons. As such, the output data obtained by ERDOS can be easily integrated and further analysed in MSExcel.

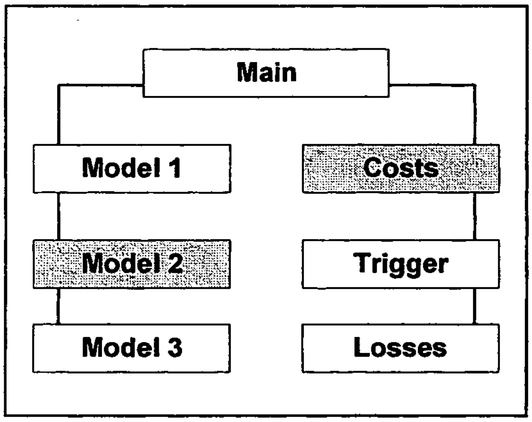
Sub cmdReturn

The procedure *cmdReturn* unloads the current form and returns to the form *frmMainMenu*.

Sub cmdAbout

The procedure *cmdAbout* loads the form *frmAbout*, that contains some general information with respect to the ERDOS-software.

6.1.2 frmmodel2_C



Sub cmdModel2_Costs

Sub cmdOutputFile

Sub cmdReturn

Sub cmdAbout

The form *frmmodel2_C* makes use of the procedure *cmdModel2_Costs*. It also uses the procedures *cmdOutputFile*, *cmdReturn* and *cmdAbout*, already discussed above (6.1.1).

Sub cmdModel2_Costs

The procedure *cmdModel2_Costs* is very similar to the procedure *cmdModel1_Costs* described in paragraph 6.1.1.

However, as a particular period of time is necessary to shut down the industrial facilities, the workers can no longer be evacuated immediately. As such, the costs of evacuation are two-fold: the purely economic costs of evacuation (cf. above) and the expected costs of the health effects, the evacuation decision notwithstanding. The latter costs depend a.o. on the estimated severity of the release at the time the evacuation is decided upon, the time required to shut down the industrial installations and the probability of the release taking place in the period of time (some) industrial workers have to remain on the industrial site.

The flowchart diagram for this procedure is given in Figure 18. Note that the only difference with respect to the flowchart in Figure 17 consists in the calculation of the costs of evacuation.

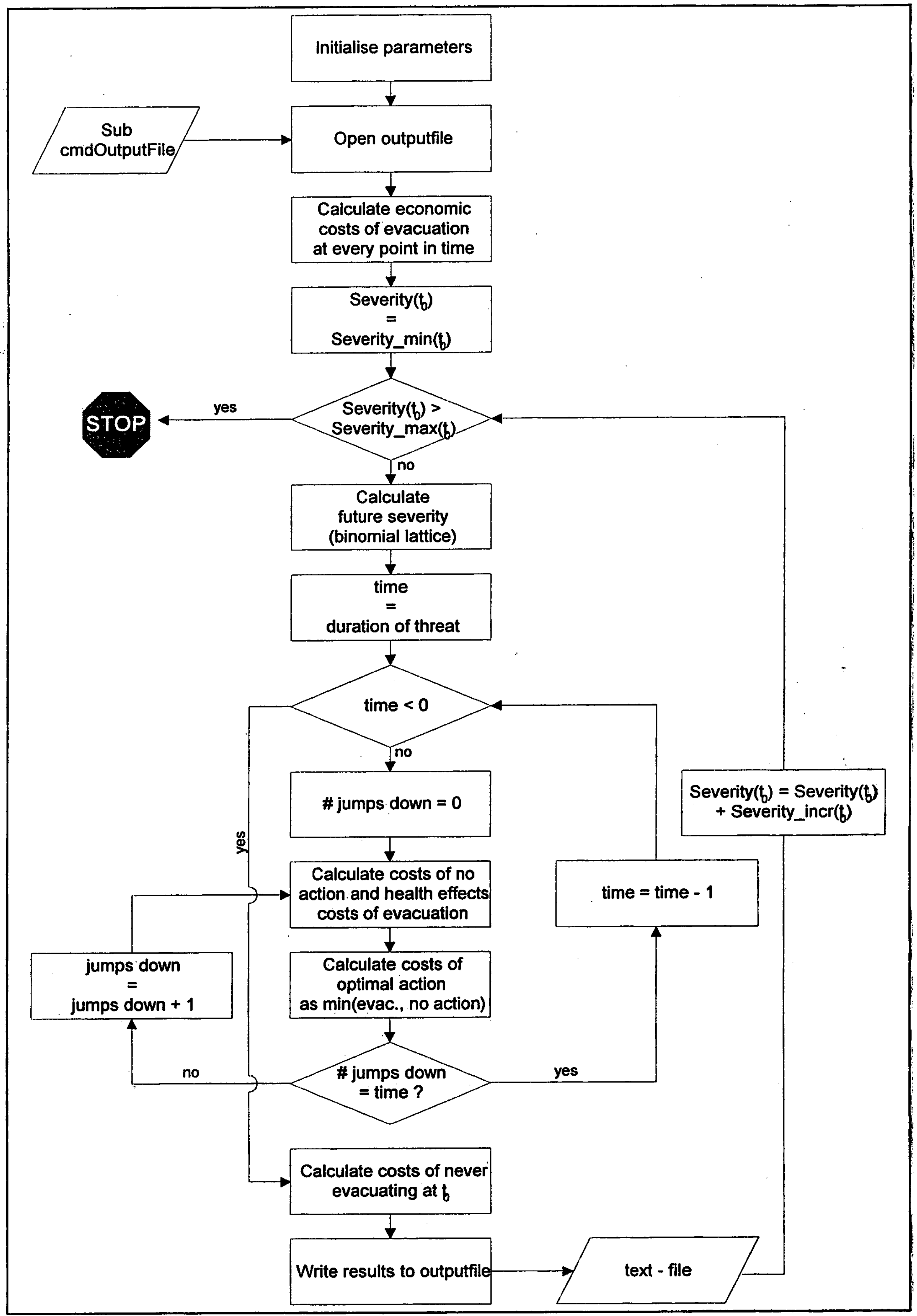
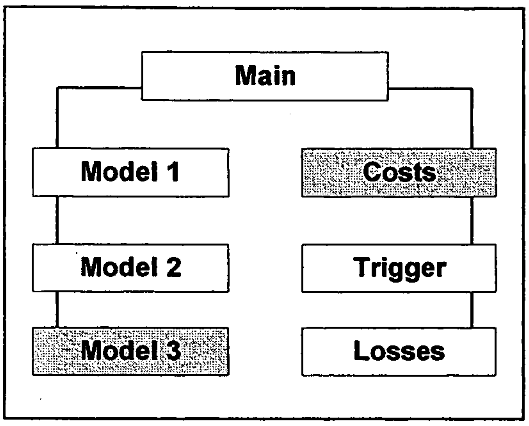


Figure 18. Flowchart for the procedure *cmdModel2_Costs.*

6.1.3 frmmodel3_C



Sub cmdModel3_Costs
Sub cmdOutputFile
Sub cmdReturn
Sub cmdAbout

The form *frmmodel3_C* makes use of the procedure *cmdModel3_Costs*. It also uses the procedures *cmdOutputFile*, *cmdReturn* and *cmdAbout*, already discussed above (6.1.1).

Sub cmdModel3_Costs

The procedure *cmdModel3_Costs* is very similar to the procedures *cmdModel1_Costs* and *cmdModel2_Costs* described in paragraphs 6.1.1 and 6.1.2.

As in the second model, some time is required to shut down the industrial facilities. As a consequence, the workers cannot be evacuated immediately and health effects costs have to be taken into account besides the economic costs of evacuation.

However, in this procedure it is assumed that the industrial facility can decide on the way in which to shut down its production processes, i.e. in a fast (but expensive), or in a slower (and economic more efficient) way. Therefore, at every point in time the decision maker should compare the resulting costs of taking no action, evacuating the industrial factory fastly, or evacuating the factory slowly.

The resulting flowchart diagram is given in Figure 19.

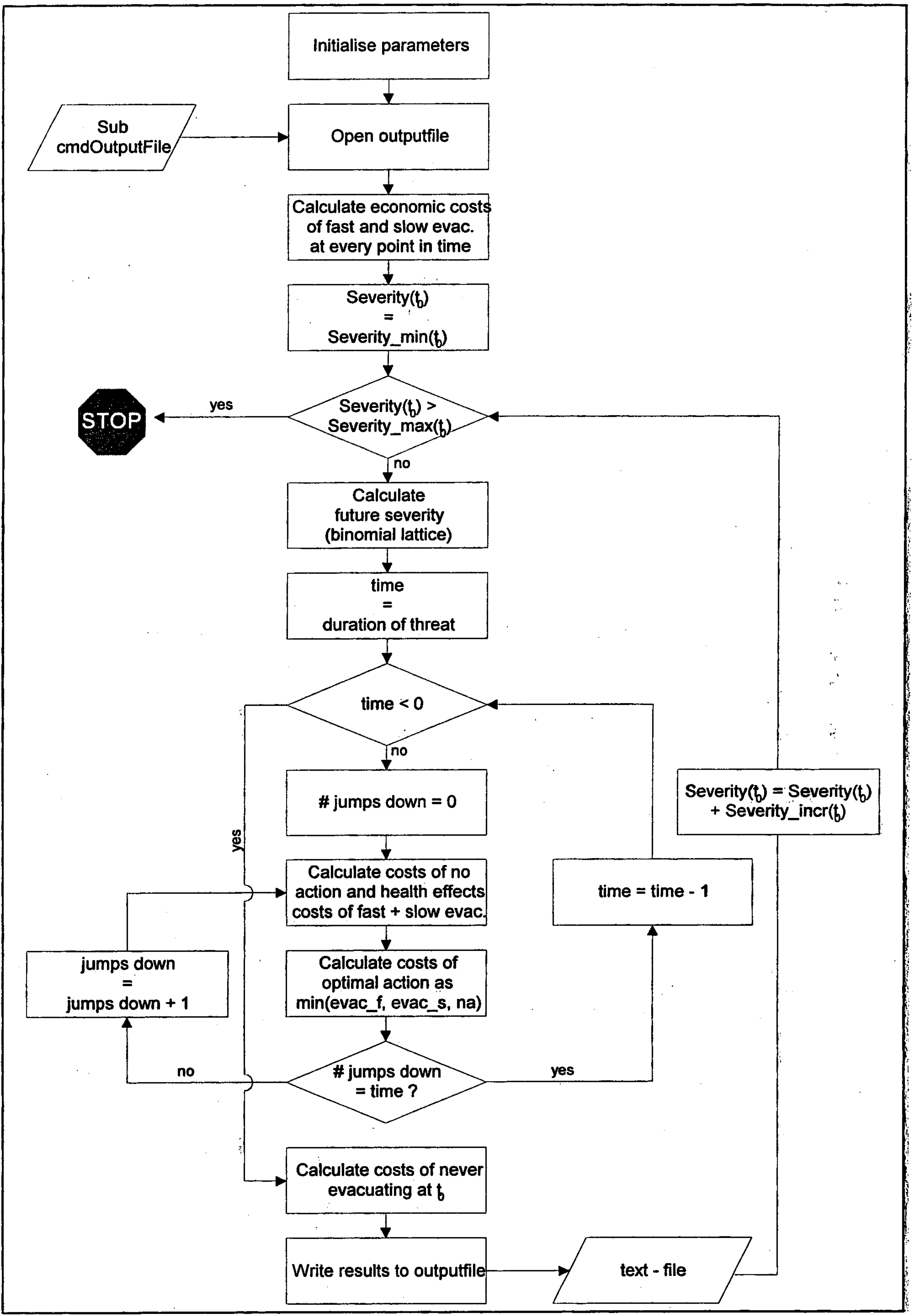


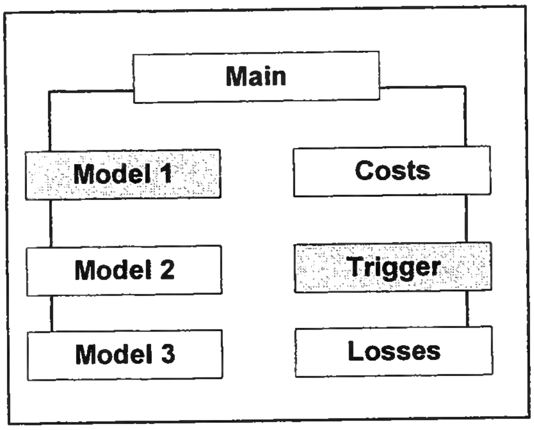
Figure 19. Flowchart for the procedure *cmdModel3_Costs*

6.2 Sub cmdCalcCriticalSeverity

The procedure *cmdCalcCriticalSeverity* calculates at every point in time the severity that will trigger immediate evacuation in case it is exceeded, i.e. the free boundary.

The procedure *cmdCalcCriticalSeverity* unloads the form *frmMainMenu.* Afterwards *frmmodel1_X*, *frmmodel2_X* or *frmmodel3_X* is loaded depending on the model that is selected to be used in the main menu.

6.2.1 frmmodel1_X



Sub cmdModel1_Trigger

Sub cmdOutputFile

Sub cmdReturn

Sub cmdAbout

The form *frmmodel1_X* makes use of the procedure *cmdModel1_Trigger.* It also uses the procedures *cmdOutputFile*, *cmdReturn* and *cmdAbout*, already discussed above (6.1.1).

cmdModel1_Trigger

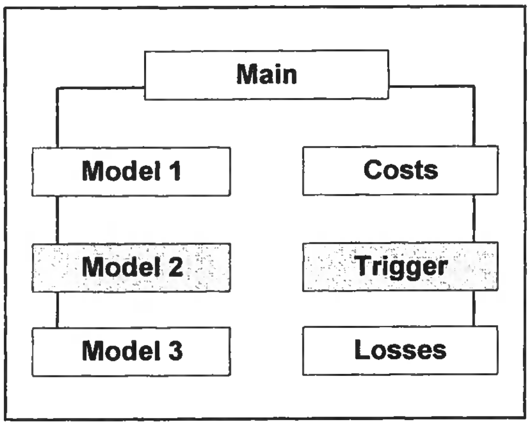
The procedure *cmdModel1_Trigger* operates as follows:

- Initialising the modelparameters.
- Opening the outputfile that has previously been determined by the user.
- Determining the costs of evacuation at point in time.
  These evacuation costs consist of three components:
  - the costs C_{sd} of shutting down the installations;
  - the costs C_{ad} of the lost added value during the period of shut-down;
  - the start-up costs C_{su} at the end of the alarm situation.
- Determining the critical severity at every point in time triggering immediate evacuation.
  - Determining the evolution of the estimated severity of the potential release from the time at which the trigger level is calculated until the end of the threat, in a recombining binomial lattice (forward calculation).
  - Determining for these time periods, the costs of taking no action (backward calculation).
    These costs consist of two parts: the monetary costs of health effects in case a release would take place in the next time period on the one hand, and the (discounted) costs that would potentially result in later time periods in case a release does not take place in the next time period, on the other hand.
  - Determining for these time periods, the costs of the optimal action (backward calculation).
    The optimal action and its associated costs, is determined by selecting the action (evacuation *vs.* no action) that leads to the lowest expected costs.

  - This procedure is repeated until the optimal action at the time the trigger level is calculated, switches from "no action" to "evacuation". The particular severity for which this is the case, is the trigger level at that point in time.
- Writing the results to the outputfile.
- Ending the analysis.

Figure 20 gives the flowchart for this procedure.

6.2.2 frmmodel2_X



Sub cmdModel2_Trigger
Sub cmdOutputFile
Sub cmdReturn
Sub cmdAbout

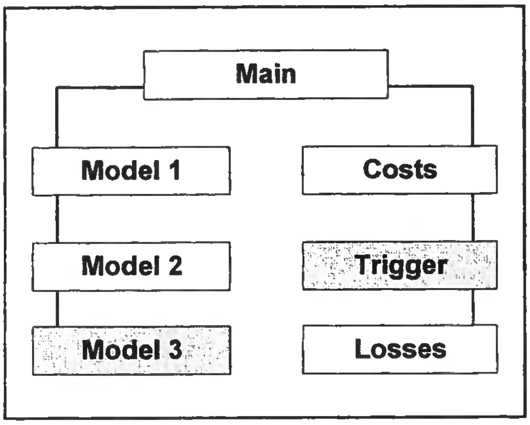
The form *frmmodel2_X* makes use of the procedure *cmdModel2_Trigger*. It also uses the procedures *cmdOutputFile*, *cmdReturn* and *cmdAbout*, already discussed above (6.1.1).

Sub cmdModel2_Trigger

The procedure *cmdModel2_Trigger* is very similar to the procedure *cmdModel1_Trigger* described in paragraph 6.2.1.

However, a particular period of time is necessary to shut down the industrial facilities and as such, the workers can no longer be evacuated immediately. The costs of evacuation are two-fold: the purely economic costs of evacuation (cf. above) and the expected costs of the health effects, the evacuation decision notwithstanding. The latter costs depend a.o. on the estimated severity of the release at the time evacuation is decided upon, the time required to shut down the industrial installations and the probability of the release taking place in the period of time (some) industrial workers have to remain on the industrial site.

6.2.3 frmmodel3_X



Sub cmdModel3_Trigger
Sub cmdOutputFile
Sub cmdReturn
Sub cmdAbout

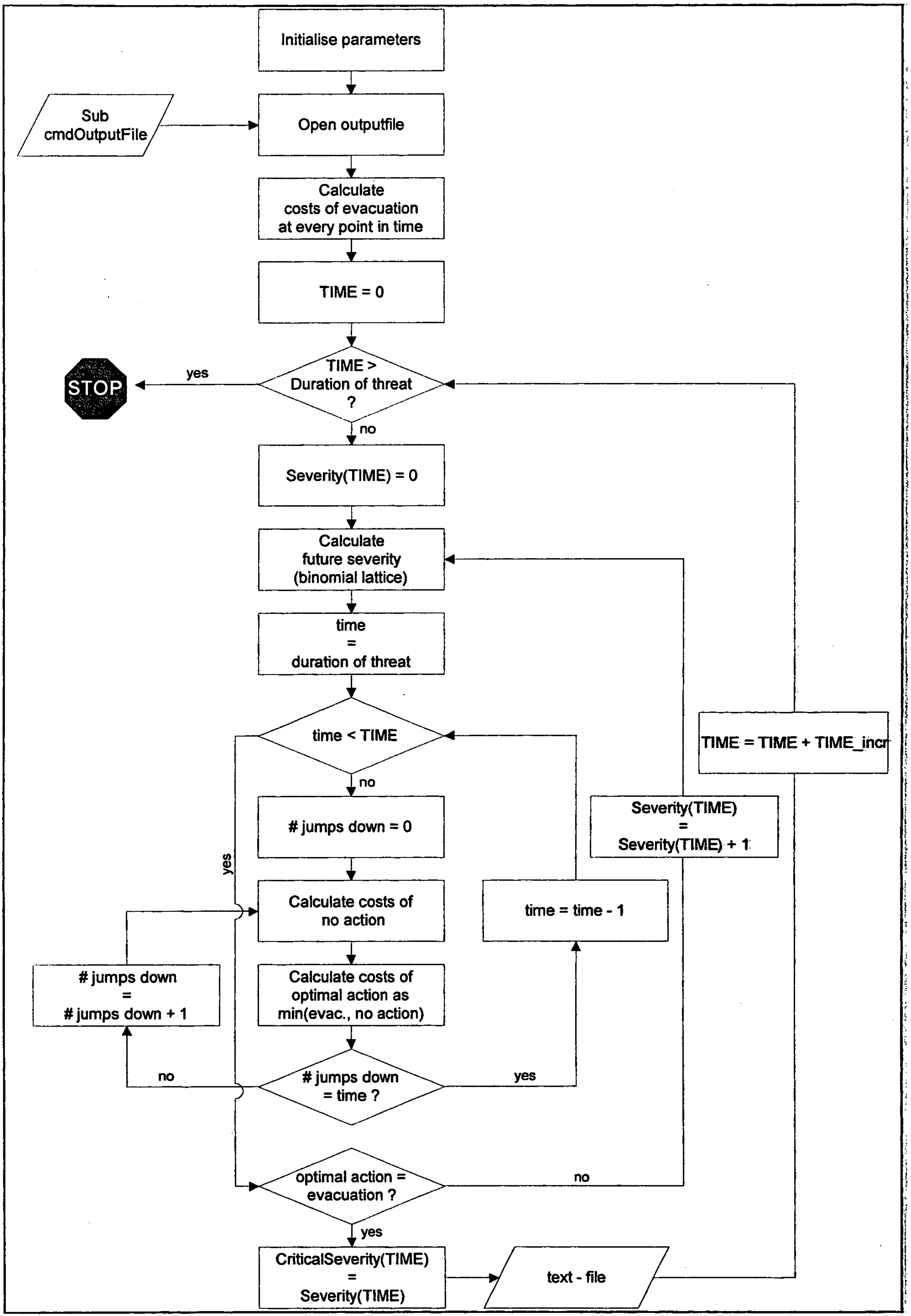


Figure 20. Flowchart for the procedure *cmdModel1_Trigger.*

The form *frmmodel3_X* makes use of the procedure *cmdModel3_Trigger*. It also uses the procedures *cmdOutputFile*, *cmdReturn* and *cmdAbout*, already discussed above (6.1.1).

Sub cmdModel3_Trigger

The procedure *cmdModel3_Trigger* is very similar to the procedures *cmdModel1_Trigger* and *cmdModel2_Trigger* described in paragraphs 6.2.1 and 6.2.2.

As in the second model, some time is required to shut down the industrial facilities. As a consequence, the workers cannot be evacuated immediately and health effects costs have to be taken into account besides the economic costs of evacuation.

However, in this procedure it is assumed that the industrial facility can decide on the way in which to shut down its production processes, i.e. in a fast (and safe), or in a slower (and safe and economic) way. Therefore, trigger levels for both fast and slow evacuation have to be derived.

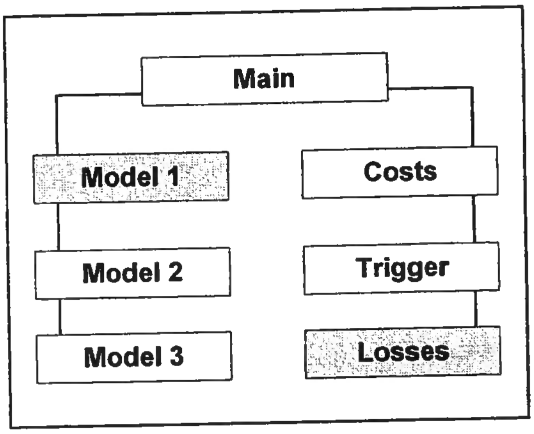
The flowchart diagram for this procedure is not included here for reasons of strong similarity with ideas already having been developed above (cf. 6.1.3 *vs.* 6.1.1). The only difference with respect to the flowchart in Figure 20 will consist in the calculation of the costs of evacuation and in going through the procedure twice: once for the fast and once for the slow evacuation alternative.

6.3 Sub cmdCalcLosses

The procedure *cmdCalcLosses* calculates the losses that might be expected from losing time during the initial stages of the decision process, as a function of the initially estimated severity of the potential release.

The procedure *cmdCalcCosts* unloads the form *frmMainMenu*. Afterwards *frmmodel1_L*, *frmmodel2_L* or *frmmodel3_L* is loaded depending on the model that is selected to be used.

6.3.1 frmmodel1_L



Sub cmdModel1_Losses
Sub cmdOutputFile
Sub cmdReturn
Sub cmdAbout

The form *frmmodel1_L* makes use of the procedure *cmdModel1_Losses*. It also uses the procedures *cmdOutputFile*, *cmdReturn* and *cmdAbout*, already discussed above (6.1.1).

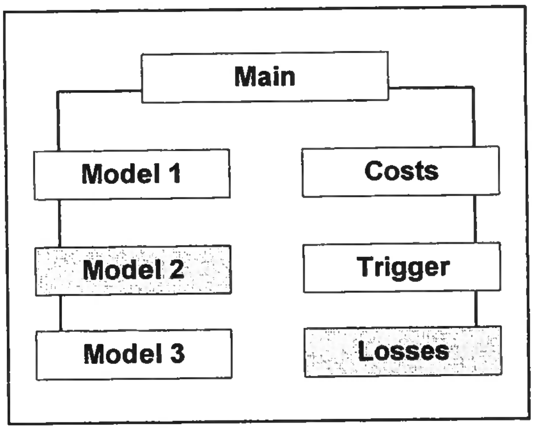
Sub cmdModel1_Losses

The procedure *cmdModel1_Losses* proceeds as follows:

- Initialising the modelparameters.
- Opening the outputfile that has previously been determined by the user.
- Determining the costs of evacuation at every point in time.
- These evacuation costs consist of three components:
  - the costs C_{sd} of shutting down the installations;
  - the costs C_{ad} of the lost added value during the period of shut-down;
  - the start-up costs C_{su} at the end of the alarm situation.
- Determining the costs that are dependent on the evolution of the estimated severity of the potential release.
  - Determining the evolution of the severity of the potential release as a function of time in a recombining binomial lattice (forward calculation).
  - Determining the expected costs of the optimal initial action in case no time is lost:
    - Determining at every point in time, the costs of taking no action (backward calculation).
      These costs consist of two parts: the monetary costs of health effects in case a release would take place in the next time period on the one hand, and the (discounted) costs that would potentially result in later time periods in case a release does not take place in the next time period on the other hand.
    - Determining at every point in time, the costs of the optimal action (backward calculation).
    - The optimal action and its associated costs, is determined by selecting the action (evacuation *vs.* no action) that leads to the lowest expected costs.
  - Determining the expected costs in case optimal actions are taken *after* the 'loss of time'-periods, but no actions are taken (i.e. can be taken) *during* the 'loss of time'-periods.
- Writing the results to the output file.
- Ending the analysis.

Figure 21a, b presents the flowchart for this procedure.

6.3.2 frmmodel2_L



Sub cmdModel2_Losses
Sub cmdOutputFile
Sub cmdReturn
Sub cmdAbout

The form *frmmodel2_L* makes use of the procedure *cmdModel2_Losses*. It also uses the procedures *cmdOutputFile*, *cmdReturn* and *cmdAbout*, already discussed above (6.1.1).

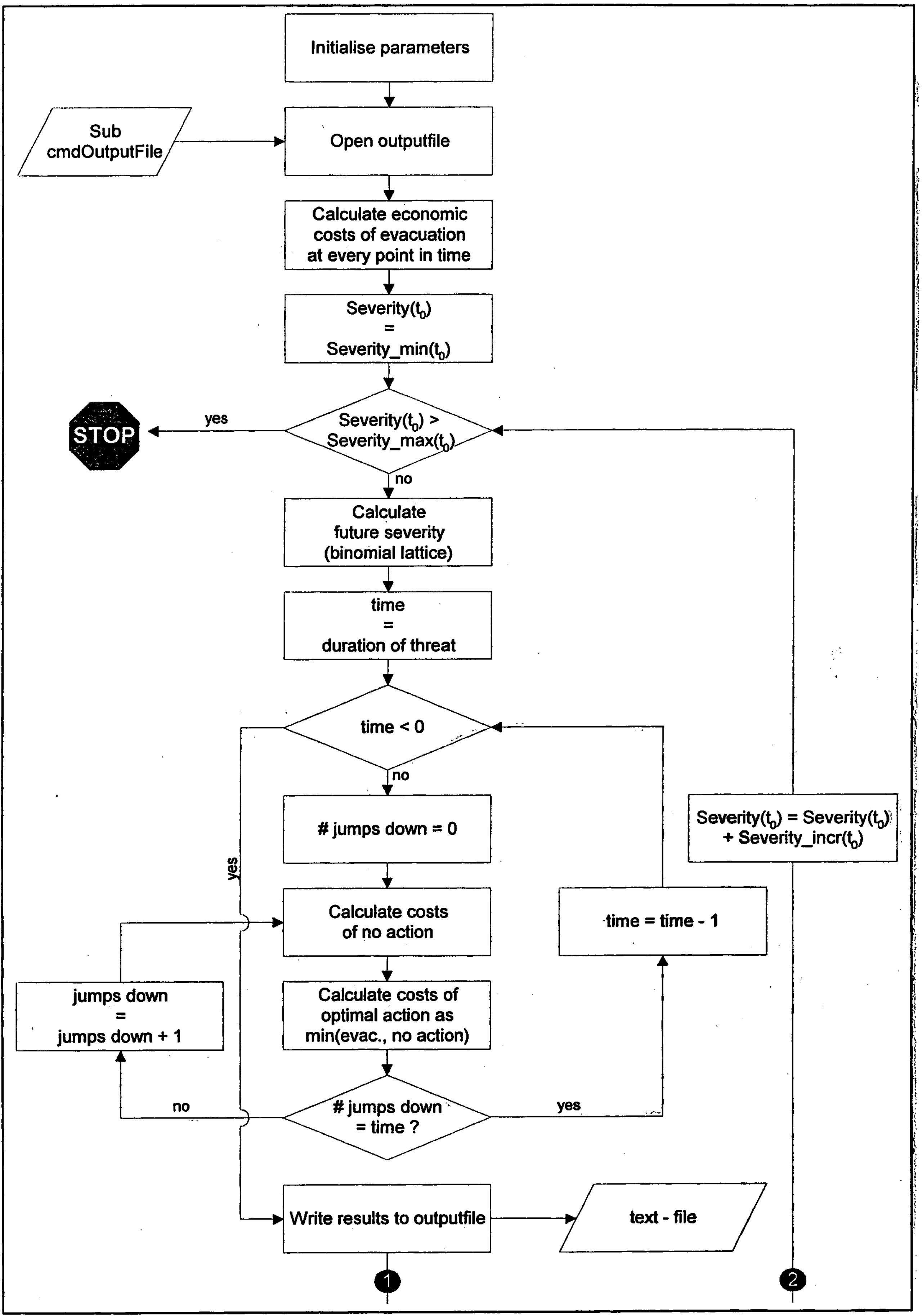


Figure 21a. Flowchart for the procedure *cmdModel1_Losses*

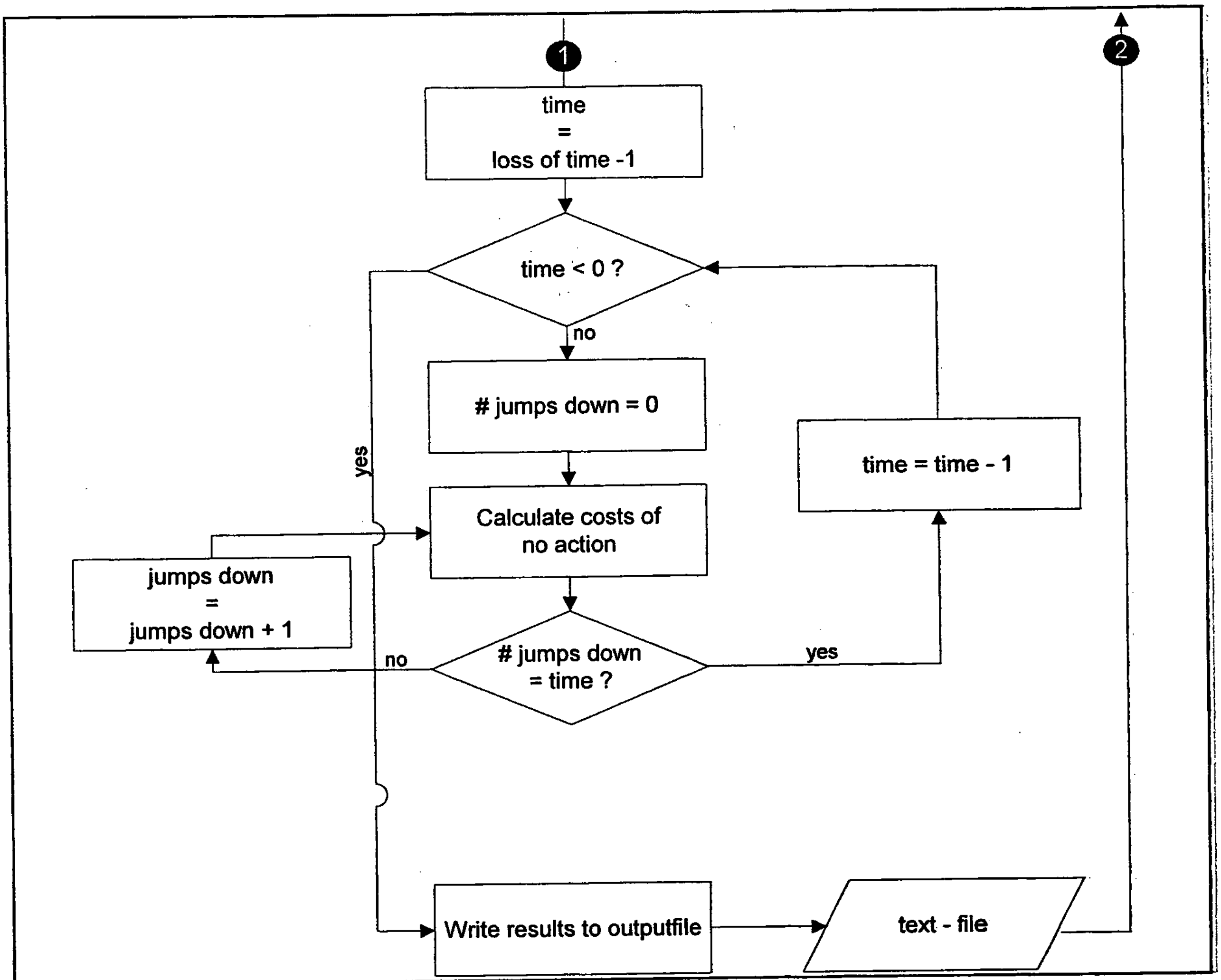


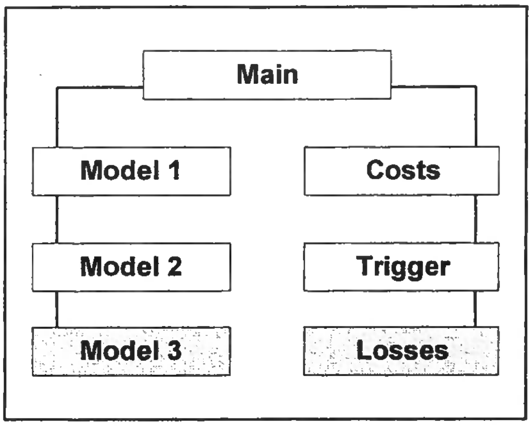
Figure 21b. Continued flowchart for the procedure *cmdModel1_Losses*

Sub cmdModel2_Losses

The procedure *cmdModel2_Losses* is very similar to the procedure *cmdModel1_Losses* described in paragraph 6.3.1.

However, a particular period of time is necessary to shut down the industrial facilities and as such, the workers can no longer be evacuated immediately. The costs of evacuation are again two-fold: the purely economic costs of evacuation (cf. above) and the expected costs of the health effects, the evacuation decision notwithstanding. The latter costs depend a.o. on the estimated severity of the release at the time the evacuation is decided upon, the time required to shut down the industrial installations and the probability of the release taking place in the period of time (some) industrial workers have to remain on the industrial site.

6.3.3 frmmodel3_L



Sub cmdModel3_Losses

Sub cmdOutputFile

Sub cmdReturn

Sub cmdAbout

The form *frmmodel3_L* makes use of the procedure *cmdModel3_Losses*. It also uses the procedures *cmdOutputFile*, *cmdReturn* and *cmdAbout*, already discussed above (6.1.1).

Sub cmdModel3_Losses

The procedure *cmdModel3_Losses* is very similar to the procedures *cmdModel1_Losses* and *cmdModel2_Losses* described in paragraphs 6.3.1 and 6.3.2.

As in the second model, some time is required to shut down the industrial facilities. As a consequence, the workers cannot be evacuated immediately and health effects costs have to be taken into account besides the economic costs of evacuation.

However, in this procedure it is assumed that the industrial facility can decide on the way in which to shut down its production processes: fast or slow.

The flowchart diagram for this procedure is not included here for reasons of strong similarity with ideas already having been developed above (cf. 6.1.3 *vs.* 6.1.1). The only difference with respect to the flowchart in Figure 21a,b consists in the calculation of the costs of the evacuation decision and in going through the procedure twice: once for the fast and once for the slow evacuation alternative.

6.4 Functions

ERDOS makes use of the following defined functions

Min2(x, y)
Returns the minimum of the two variables *x* and *y*

Min3(x, y, z)
Returns the minimum of the three variables *x*, *y* and *z*

Fraction(x, y)
Returns the fraction of the workers still present at the industrial facility *x* periods after the start of the evacuation, in case *y* periods are required to evacuate all workers.

TotalFraction(p, r, x, y, z)
Returns the expected discounted total fraction of the workers that will be exposed to radiation in case the probability of the release taking place in a particular period is given by *p*, evacuation is started at time *x*, while *y* periods are required to evacuate all workers. The duration of the threat is given by *z*, the one time period discount rate by *r*.

TotalProbabilityRelease(p, r)
Returns the total discounted probability of a release effectively taking please during the threat in case the probability of a release in a particular time period is given by *p* and the one time period discount rate by *r*.

– Total Fraction ?

– TotalProbRelease ?

discount ?

CONCLUSION

In this paper, the ERDOS (Emergency Response Decisions as problems of Optimal Stopping) - software was presented. ERDOS is a stochastic dynamic program that deals with the decision problem of preventively evacuating the workers of an industrial factory threatened by a nuclear accident taking place with a particular probability in a nuclear power plant nearby, as one of optimal stopping.

In this decision context, it was shown that the decision maker initially holds an American call option allowing him to postpone the evacuation decision to a certain extent, and to observe the further evolution of the severity of the release - in case it would effectively take place. As such, he has to decide on the optimal point in time to 'exercise' this option, i.e. to take the irreversible decision of shutting down the industrial processes and evacuating the industrial workers.

The uncertain evolution of the estimated severity of the possible release over time, is first modelled in ERDOS by means of a binomial tree. The preventive evacuation decision problem itself, is then solved by means of a backward calculation strategy, starting at the end of the time horizon of interest, i.e. the expected duration of the threat, and folding backward until the initial point in time, i.e. the time of the initial alarm, is reached.

Three models of the industrial company, with increasing degree of complexity, are integrated in the software. The first model assumes that the industrial production processes can be shut down (and the workers be evacuated) instantaneously. The second model, however, takes into account that this shut down requires a particular period of time. Finally, it is assumed in the third model that the industrial company can choose between a fast (but expensive) and a slow (and economic more efficient) shut-down mode, with associated duration.

For each of these models, ERDOS allows to calculate the expected costs of the optimal intervention strategy, i.e. a strategy that minimises both the immediate costs and the expected future costs knowing that subsequent decisions will be taken optimally too, contingent on the state of nature that is revealed at that time. Furthermore, the free boundary of the evacuation decision problem can be determined. This free boundary represents the level of the severity of the potential release as a function of time that will trigger immediate evacuation in case it is exceeded. Finally, ERDOS enables to verify the financial implications of 'loosing' time during the initial stages of the decision process for instance due to the gathering of information, discussions on the intervention strategy to be followed, etc.

ACKNOWLEDGEMENTS

The author wishes to thank Tom Van Woensel (University of Antwerp, UFSIA, STEM) for the fruitful discussions and support when developing the program.

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APPENDIX 1. Overview of inputparameters

A1.1 Calculation of costs (model 1)

Nuclear threat	
Initial severity (min)	The smallest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (max)	The largest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (incr)	The increment in the estimate of the initial severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Probability up	The risk-neutral probability of the severity of the potential release making an upward jump in every time period.
Probability down	The risk-neutral probability of the severity of the potential release making a downward jump in every time period.
Impact up	A factor (>1) by which the severity of the potential release is multiplied in case of an upward jump.
Impact down	A factor (<1) by which the severity of the potential release is multiplied in case of a downward jump.
Probability release	The probability of the release taking place in a particular time period, given that a release has not occurred in the previous time periods.
Duration of threat	The number of periods during which there is a strictly positive probability of a release effectively taking place (≤ 500).
Industrial factory	
Added value	The added value (MBef) that - in normal working conditions - would have been created by the firm during one time period.
Discount rate	The continuously compounded yearly discount rate.
Alpha-value	The monetary value (MBef/Man.Sv) assigned to one unit of collective dose.
Shut-down mode	
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase: continued loss of added value, loss of market share, etc.

Table A1.1 Inputparameters (calculation of costs, model 1).

A1.2 Calculation of costs (model 2)

Nuclear threat	
Initial severity (min)	The smallest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (max)	The largest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (incr)	The increment in the estimate of the initial severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Probability up	The risk-neutral probability of the severity of the potential release making an upward jump in every time period.
Probability down	The risk-neutral probability of the severity of the potential release making a downward jump in every time period.
Impact up	A factor (>1) by which the severity of the potential release is multiplied in case of an upward jump.
Impact down	A factor (<1) by which the severity of the potential release is multiplied in case of a downward jump.
Probability release	The probability of the release taking place in a particular time period, given that a release has not occurred in the previous time periods.
Duration of threat	The number of periods during which there is a strictly positive probability of a release effectively taking place (≤ 500).
Industrial factory	
Added value	The added value (MBef) that - in normal working conditions - would have been created by the firm during one time period.
Discount rate	The continuously compounded yearly discount rate.
Alpha-value	The monetary value (MBef/Man.Sv) assigned to one unit of collective dose.
Shut-down mode	
Duration of shut-down	The number of time periods required to shut down the industrial company.
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase: continued loss of added value, loss of market share, etc.

Table A1.2 Inputparameters (calculation of costs, model 2).

A1.3 Calculation of costs (model 3)

Nuclear threat	
Initial severity (min)	The smallest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (max)	The largest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (incr)	The increment in the estimate of the initial severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Probability up	The risk-neutral probability of the severity of the potential release making an upward jump in every time period.
Probability down	The risk-neutral probability of the severity of the potential release making a downward jump in every time period.
Impact up	A factor (>1) by which the severity of the potential release is multiplied in case of an upward jump.
Impact down	A factor (<1) by which the severity of the potential release is multiplied in case of a downward jump.
Probability release	The probability of the release taking place in a particular time period, given that a release has not occurred in the previous time periods.
Duration of threat	The number of periods during which there is a strictly positive probability of a release effectively taking place (≤ 500).
Industrial factory	
Added value	The added value (MBef) that - in normal working conditions - would have been created by the firm during one time period.
Discount rate	The continuously compounded yearly discount rate.
Alpha-value	The monetary value (MBef/Man.Sv) assigned to one unit of collective dose.
Shut-down mode	
FAST SHUT-DOWN	
Duration of shut-down	The minimal number of time periods required to shut down the industrial company in a safe way.
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes in a safe way: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase after a safe shut-down: continued loss of added value, loss of market share, etc.

SLOW SHUT-DOWN	
Duration of shut-down	The number of time periods required to shut down the industrial company in a safe and economic way.
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes in a safe and economic way: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase after a safe and economic shut-down: continued loss of added value, loss of market share, etc.

Table A1.3 Inputparameters (calculation of costs, model 3).

A1.4 Calculation of trigger levels (model 1)

Nuclear threat	
Probability up	The risk-neutral probability of the severity of the potential release making an upward jump in every time period.
Probability down	The risk-neutral probability of the severity of the potential release making a downward jump in every time period.
Impact up	A factor (>1) by which the severity of the potential release is multiplied in case of an upward jump.
Impact down	A factor (<1) by which the severity of the potential release is multiplied in case of a downward jump.
Probability release	Probability of the release taking place in a particular time period, given that a release has not occurred in the previous time periods.
Duration of threat	The number of periods during which there is a strictly positive probability of a release effectively taking place (≤ 500).
Period (incr)	The increment in the time periods for which the critical severity, triggering evacuation, is calculated.
Industrial factory	
Added value	The added value (MBef) that - in normal working conditions - would have been created by the firm during one time period.
Discount rate	The continuously compounded yearly discount rate.
Alpha-value	The monetary value (MBef/Man.Sv) assigned to one unit of collective dose.
Shut-down mode	
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase: continued loss of added value, loss of market share, etc.

Table A1.4 Inputparameters (calculation of trigger levels, model 1).

A1.5 Calculation of trigger levels (model 2)

Nuclear threat	
Probability up	The risk-neutral probability of the severity of the potential release making an upward jump in every time period.
Probability down	The risk-neutral probability of the severity of the potential release making a downward jump in every time period.
Impact up	A factor (>1) by which the severity of the potential release is multiplied in case of an upward jump.
Impact down	A factor (<1) by which the severity of the potential release is multiplied in case of a downward jump.
Probability release	The probability of the release taking place in a particular time period, given that a release has not occurred in the previous time periods.
Duration of threat	The number of periods during which there is a strictly positive probability of a release effectively taking place (≤ 500).
Period (incr)	The increment in the time periods for which the critical severity, triggering evacuation, is calculated.
Industrial factory	
Added value	The added value (MBef) that - in normal conditions - would have been created by the firm during one time period.
Discount rate	The continuously compounded yearly discount rate.
Alpha-value	The monetary value (MBef/Man.Sv) assigned to one unit of collective dose.
Shut-down mode	
Duration of shut-down	The number of time periods required to shut down the industrial company.
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase: continued loss of added value, loss of market share, etc.

Table A1.5 Inputparameters (calculation of trigger levels, model 2).

A1.6 Calculation of trigger levels (model 3)

Nuclear threat	
Probability up	The risk-neutral probability of the severity of the potential release making an upward jump in every time period.
Probability down	The risk-neutral probability of the severity of the potential release making a downward jump in every time period.
Impact up	A factor (>1) by which the severity of the potential release is multiplied in case of an upward jump.
Impact down	A factor (<1) by which the severity of the potential release is multiplied in case of a downward jump.
Probability release	The probability of the release taking place in a particular time period, given that a release has not occurred in the previous time periods.
Duration of threat	The number of periods during which there is a strictly positive probability of a release effectively taking place (≤ 500).
Period (incr)	The increment in the time periods for which the critical severity, triggering fast or slow evacuation, is calculated.
Industrial factory	
Added value	The added value (MBef) created by the company during one time period.
Discount rate	The continuously compounded yearly discount rate.
Alpha-value	The monetary value (MBef/Man.Sv) assigned to one unit of collective dose.
Shut-down mode	
FAST SHUT-DOWN	
Duration of shut-down	The minimal number of time periods required to shut down the industrial company in a safe way.
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes in a safe way: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase after a safe shut-down: continued loss of added value, loss of market share, etc.
SLOW SHUT-DOWN	
Duration of shut-down	The number of time periods required to shut down the industrial company in a safe and economic way.
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes in a safe and economic way: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase after a safe and economic shut-down: continued loss of added value, loss of market share, etc.

Table A1.6 Inputparameters (calculation of trigger levels, model 3).

A1.7 Calculation of losses due to the loss of time (model 1)

Nuclear threat	
Initial severity (min)	The smallest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (max)	The largest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (incr)	The increment in the estimate of the initial severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Probability up	The risk-neutral probability of the severity of the potential release making an upward jump in every time period.
Probability down	The risk-neutral probability of the severity of the potential release making a downward jump in every time period.
Impact up	A factor (>1) by which the severity of the potential release is multiplied in case of an upward jump.
Impact down	A factor (<1) by which the severity of the potential release is multiplied in case of a downward jump.
Probability release	The probability of the release taking place in a particular time period, given that a release has not occurred in the previous time periods.
Duration of threat	The number of periods during which there is a strictly positive probability of a release effectively taking place (≤ 500).
Industrial factory	
Added value	The added value (MBef) that - in normal working conditions - would have been created by the firm during one time period.
Discount rate	The continuously compounded yearly discount rate.
Alpha-value	The monetary value (MBef/Man.Sv) assigned to one unit of collective dose.
Shut-down mode	
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase: continued loss of added value, loss of market share, etc.
Loss of time	
Loss of time	The number of time periods lost at the beginning of the decision process due to information gathering, discussion, etc.

Table A1.7 Inputparameters (calculation of losses due to the loss of time, model 1).

A1.8 Calculation of losses due to the loss of time (model 2)

Nuclear threat	
Initial severity (min)	The smallest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (max)	The largest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (incr)	The increment in the estimate of the initial severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Probability up	The risk-neutral probability of the severity of the potential release making an upward jump in every time period.
Probability down	The risk-neutral probability of the severity of the potential release making a downward jump in every time period.
Impact up	A factor (>1) by which the severity of the potential release is multiplied in case of an upward jump.
Impact down	A factor (<1) by which the severity of the potential release is multiplied in case of a downward jump.
Probability release	The probability of the release taking place in a particular time period, given that a release has not occurred in the previous time periods.
Duration of threat	The number of periods during which there is a strictly positive probability of a release effectively taking place (≤ 500).
Industrial factory	
Added value	The added value (MBef) that - in normal working conditions - would have been created by the firm during one time period.
Discount rate	The continuously compounded yearly discount rate.
Alpha-value	The monetary value (MBef/Man.Sv) assigned to one unit of collective dose.
Shut-down mode	
Duration of shut-down	The number of time periods required to shut down the industrial company.
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase: continued loss of added value, loss of market share, etc.
Loss of time	
Loss of time	The number of time periods lost at the beginning of the decision process due to information gathering, discussion, etc.

Table A1.8 Inputparameters (calculation of losses due to the loss of time, model 2).

A1.9 Calculation of losses due to the loss of time (model 3)

Nuclear threat	
Initial severity (min)	The smallest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (max)	The largest initial estimate of the severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Initial severity (incr)	The increment in the estimate of the initial severity of the potential release for which the analysis will be executed. Expressed as the resulting collective dose (man.Sv) in case the release would effectively take place.
Probability up	The risk-neutral probability of the severity of the potential release making an upward jump in every time period.
Probability down	The risk-neutral probability of the severity of the potential release making a downward jump in every time period.
Impact up	A factor (>1) by which the severity of the potential release is multiplied in case of an upward jump.
Impact down	A factor (<1) by which the severity of the potential release is multiplied in case of a downward jump.
Probability release	The probability of the release taking place in a particular time period, given that a release has not occurred in the previous time periods.
Duration of threat	The number of periods during which there is a strictly positive probability of a release effectively taking place (≤ 500).
Industrial factory	
Added value	The added value (MBef) that - in normal working conditions - would have been created by the firm during one time period.
Discount rate	The continuously compounded yearly discount rate.
Alpha-value	The monetary value (MBef/Man.Sv) assigned to one unit of collective dose.
Shut-down mode	
FAST SHUT-DOWN	
Duration of shut-down	The minimal number of time periods required to shut down the industrial company in a safe way.
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes in a safe way: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase after a safe shut-down: continued loss of added value, loss of market share, etc.

SLOW SHUT-DOWN	
Duration of shut-down	The number of time periods required to shut down the industrial company in a safe and economic way.
Initial shut-down costs	The costs (MBef) incurred by the firm when shutting down its production processes in a safe and economic way: damage to installations, loss of products, etc.
Start-up costs	The costs (MBef) incurred by the firm during the start-up phase after a safe and economic shut-down: continued loss of added value, loss of market share, etc.
Loss of time	
Loss of time	The number of time periods lost at the beginning of the decision process due to information gathering, discussion, etc.

Table A1.9 Inputparameters (calculation of losses due to the loss of time, model 3).

APPENDIX 2. Overview of variables in VisualBasic program code

	Name	*Procedure*	*Type*	*Explanation*
A	alpha	cmdModel{1, 2, 3}_Costs	Single	Monetary value assigned to a unit of collective dose
		cmdModel{1, 2, 3}_Losses	Single	Monetary value assigned to a unit of collective dose
		cmdModel{1, 2, 3}_Trigger	Single	Monetary value assigned to a unit of collective dose
B	b	cmdModel{1, 2, 3}_Trigger	Integer	Time horizon of the decision problem at a particular point in time
C	Cost_evacuation (500)	cmdModel1_Costs	Single	Costs of the decision to evacuate at time I
		cmdModel1_Losses	Single	Costs of the decision to evacuate at time I
		cmdModel1_Trigger	Single	Costs of the decision to evacuate at time I
	Cost_evacuation_economic (500)	cmdModel2_Costs	Single	Economic costs of the decision to evacuate at time I
		cmdModel2_Losses	Single	Economic costs of the decision to evacuate at time I
		cmdModel2_Trigger	Single	Economic costs of the decision to evacuate at time I
	Cost_evacuation_economic_fast (500)	cmdModel3_Costs	Single	Economic costs of the decision to evacuate fastly at time I
		cmdModel3_Losses	Single	Economic costs of the decision to evacuate fastly at time I
		cmdModel3_Trigger	Single	Economic costs of the decision to evacuate fastly at time I
	Cost_evacuation_economic_slow (500)	cmdModel3_Costs	Single	Economic costs of the decision to evacuate slowly at time I
		cmdModel3_Losses	Single	Economic costs of the decision to evacuate slowly at time I
		cmdModel3_Trigger	Single	Economic costs of the decision to evacuate slowly at time I
	Cost_evacuation_health (500, 500)	cmdModel2_Costs	Single	Health effects costs of the decision to evacuate at time I, after J downward jumps
		cmdModel2_Losses	Single	Health effects costs of the decision to evacuate at time I, after J downward jumps
		cmdModel2_Trigger	Single	Health effects costs of the decision to evacuate at time I, after J downward jumps
	Cost_evacuation_health_fast (500, 500)	cmdModel3_Costs	Single	Health effects costs of the decision to evacuate fastly at time I, after J downward jumps
		cmdModel3_Losses	Single	Health effects costs of the decision to evacuate fastly at time I, after J downward jumps
		cmdModel3_Trigger	Single	Health effects costs of the decision to evacuate fastly at time I, after J downward jumps

Name	***Procedure***	***Type***	***Explanation***
Cost_evacuation_health_slow	cmdModel3_Costs	Single	Helath effects costs of the decision to evacuate slowly at time I, after J downward jumps
	cmdModel3_Losses	Single	Health effects costs of the decision to evacuate slowly at time I, after J downward jumps
	cmdModel3_Trigger	Single	Health effects costs of the decision to evacuate slowly at time I, after J downward jumps
Costs_never	cmdModel{1, 2, 3}_Costs	Single	Costs of the decision to never evacuate
Costs_no_action	cmdModel{1, 2, 3}_Costs	Single	Costs of the decision to take no action at a particular point in time
	cmdModel{1, 2, 3}_Losses	Single	Costs of the decision to take no action at a particular point in time
	cmdModel{1, 2, 3}_Trigger	Single	Costs of the decision to take no action at a particular point in time
Costs_option(500, 500)	cmdModel{1, 2, 3}_Costs	Single	Costs of optimal action at time I, after J downward jumps
	cmdModel{1, 2, 3}_Losses	Single	Costs of optimal action at time I, after J downward jumps
	cmdModel{1, 2, 3}_Trigger	Single	Costs of optimal action at time I, after J downward jumps
Costs_option_losses (500, 500)	cmdModel{1, 2, 3}_Losses	Single	Costs of 'optimal' action at time I, after J downward jumps if time is lost
C_ad	cmdModel{1, 2, 3}_Costs	Single	Added value created by the industrial company during 1 time period
	cmdModel{1, 2, 3}_Losses	Single	Added value created by the industrial company during 1 time period
	cmdModel{1, 2, 3}_Trigger	Single	Added value created by the industrial company during 1 time period
CriticalSeverity	cmdModel{1, 2}_Trigger	Single	Critical severity triggering immediate evacuation
CriticalSeverity_fast	cmdModel3_Trigger	Single	Critical severity triggering immediate fast evacuation
CriticalSeverity_slow	cmdModel3_Trigger	Single	Critical severity triggering immediate slow evacuation
C_sd	cmdModel{1, 2}_Costs	Single	Costs of shutting down the industrial company
	cmdModel{1, 2}_Losses	Single	Costs of shutting down the industrial company
	cmdModel{1, 2}_Trigger	Single	Costs of shutting down the industrial company
C_sd_f	cmdModel3_Costs	Single	Costs of fastly shutting down the industrial company
	cmdModel3_Losses	Single	Costs of fastly shutting down the industrial company
	cmdModel3_Trigger	Single	Costs of fastly shutting down the industrial company
C_sd_s	cmdModel3_Costs	Single	Costs of slowly shutting down the industrial company
	cmdModel3_Losses	Single	Costs of slowly shutting down the industrial company
	cmdModel3_Trigger	Single	Costs of slowly shutting down the industrial company

	Name	Procedure	Type	Explanation
	C_su	cmdModel{1, 2}_Costs	Single	Costs of restarting the industrial company
		cmdModel{1, 2}_Losses	Single	Costs of restarting the industrial company
		cmdModel{1, 2}_Trigger	Single	Costs of restarting the industrial company
D	D_sd	cmdModel2_Costs	Integer	Duration of shut-down
		cmdModel2_Losses	Integer	Duration of shut-down
		cmdModel2_Trigger	Integer	Duration of shut-down
	D_sd_f	cmdModel3_Costs	Integer	Duration of fast shut-down
		cmdModel3_Losses	Integer	Duration of fast shut-down
		cmdModel3_Trigger	Integer	Duration of fast shut-down
	D_sd_s	cmdModel3_Costs	Integer	Duration of slow shut-down
		cmdModel3_Losses	Integer	Duration of slow shut-down
		cmdModel3_Trigger	Integer	Duration of slow shut-down
	D_t	cmdModel{1, 2, 3}_Costs	Integer	Duration of threat - 1
		cmdModel{1, 2, 3}_Losses	Integer	Duration of threat - 1
		cmdModel{1, 2, 3}_Trigger	Integer	Duration of threat - 1
	Duration	cmdModel{1, 2, 3}_Costs	Integer	Duration of threat
		cmdModel{1, 2, 3}_Losses	Integer	Duration of threat
		cmdModel{1, 2, 3}_Trigger	Integer	Duration of threat
E	Exposure_fast (b)	cmdModel3_Trigger	Single	Expected total fraction of workers exposed after fast evacuation
	Exposure_slow (b)	cmdModel3_Trigger	Single	Expected total fraction of workers exposed after slow evacuation
F	F	cmdModel{1, 2, 3}_Trigger	Integer	Sum of time at which critical severity is calculated (W) and time I
I	I_d	cmdModel{1, 2, 3}_Costs	Single	Impact on the estimated severity of one downward jump (I_d < 1)
		cmdModel{1, 2, 3}_Losses	Single	Impact on the estimated severity of one downward jump (I_d < 1)
		cmdModel{1, 2, 3}_Trigger	Single	Impact on the estimated severity of one downward jump (I_d < 1)
	I_u	cmdModel{1, 2, 3}_Costs	Single	Impact on the estimated severity of one upward jump (I_u > 1)
		cmdModel{1, 2, 3}_Losses	Single	Impact on the estimated severity of one upward jump (I_u > 1)
		cmdModel{1, 2, 3}_Trigger	Single	Impact on the estimated severity of one upward jump (I_u > 1)

	Name	**Procedure**	**Type**	**Explanation**
	I	cmdModel{1, 2, 3}_Costs	Integer	Counter, reflecting time
		cmdModel{1, 2, 3}_Losses	Integer	Counter, reflecting time
		cmdModel{1, 2, 3}_Trigger	Integer	Counter, reflecting time
J	J	cmdModel{1, 2, 3}_Costs	Integer	Counter, reflecting number of downward jumps
		cmdModel{1, 2, 3}_Losses	Integer	Counter, reflecting number of downward jumps
		cmdModel{1, 2, 3}_Trigger	Integer	Counter, reflecting number of downward jumps
P	P_d	cmdModel{1, 2, 3}_Costs	Single	Risk-neutral probability of a downward jump
		cmdModel{1, 2, 3}_Losses	Single	Risk-neutral probability of a downward jump
		cmdModel{1, 2, 3}_Trigger	Single	Risk-neutral probability of a downward jump
	P_r	cmdModel{1, 2, 3}_Costs	Single	Probability of a release taking place in a particular period
		cmdModel{1, 2, 3}_Losses	Single	Probability of a release taking place in a particular period
		cmdModel{1, 2, 3}_Trigger	Single	Probability of a release taking place in a particular period
	P_u	cmdModel{1, 2, 3}_Costs	Single	Risk-neutral probability of an upward jump
		cmdModel{1, 2, 3}_Losses	Single	Risk-neutral probability of an upward jump
		cmdModel{1, 2, 3}_Trigger	Single	Risk-neutral probability of an upward jump
R	r	cmdModel{1, 2, 3}_Costs	Single	The continuously compounded yearly discount rate
		cmdModel{1, 2, 3}_Losses	Single	The continuously compounded yearly discount rate
		cmdModel{1, 2, 3}_Trigger	Single	The continuously compounded yearly discount rate
S	Severity (500, 500)	cmdModel{1, 2, 3}_Costs	Single	Estimated severity at time I, after J downward jumps
		cmdModel{1, 2, 3}_Losses	Single	Estimated severity at time I, after J downward jumps
		cmdModel{1, 2, 3}_Trigger	Single	Estimated severity at time I, after J downward jumps
	S_incr	cmdModel{1, 2, 3}_Costs	Integer	Increment of the initially estimated severity
		cmdModel{1, 2, 3}_Losses	Integer	Increment of the initially estimated severity
	S_max	cmdModel{1, 2, 3}_Costs	Integer	Maximum value for initially estimated severity
		cmdModel{1, 2, 3}_Losses	Integer	Maximum value for initially estimated severity
	S_min	cmdModel{1, 2, 3}_Costs	Integer	Minimum value for initially estimated severity
		cmdModel{1, 2, 3}_Losses	Integer	Minimum value for initially estimated severity

	Name	Procedure	Type	Explanation
T	T_incr	cmdModel{1, 2}_Trigger	Integer	Increment of time periods
	T_l	cmdModel{1, 2}_Losses	Integer	Number of time periods lost (implying decision ≡ no action)
	T_lr	cmdModel{1, 2}_Losses	Integer	Number of time periods lost (implying decision ≡ no action) - 1
U	usrfile	cmdModel{1, 2, 3}_Costs	String	Name of outputfile
		cmdModel{1, 2, 3}_Losses	String	Name of the outputfile
		cmdModel{1, 2, 3}_Trigger	String	Name of the outputfile
		cmdOutputFile	String	Name of outputfile
W	w	cmdModel{1, 2, 3}_Trigger	Integer	Counter, reflecting time at which critical severity is calculated
Z	z	cmdModel{1, 2, 3}_Costs	Integer	Counter, reflecting initial severity
		cmdModel{1, 2, 3}_Losses	Integer	Counter, reflecting initial severity
		cmdModel{1, 2}_Trigger	Integer	Counter, reflecting intial severity
	z_f	cmdModel3_Trigger	Integer	Counter, reflecting intial severity (used in fast evacuation trigger level)
	z_s	cmdModel3_Trigger	Integer	Counter, reflecting intial severity (used in slow evacuation trigger level)

Table A2.1 Variables used in VisualBasic program code