

**A PRELIMINARY MODEL FOR
IMPROVED HAZARDOUS MATERIALS MANAGEMENT IN
THE UNITED STATES OF AMERICA-MEXICO BORDER REGION**

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ABSTRACT

Large amounts of hazardous materials (both raw, recycled and waste) are used by numerous facilities along the United States (US)-Mexico border, which has clearly lead to significant environmental problems in the region. It is well known that such problems have resulted in public and worker health problems, as well as significant costs (both direct and indirect) to the facility owners/operators and their parent corporations, and adverse socio-economic impacts in the region. Such problems will continue, and in fact may worsen, unless more effort and/or more effective hazardous materials management (*HazMatMgmt*) technologies, such as have been developed by the US Department of Energy (DOE), are implemented by these facilities.

It has been proposed that the DOE Carlsbad Area Office (DOE/CAO), because of their proximity and unique qualifications, act as the facilitator for improved HazMatMgmt in the US-Mexico border region. As a facilitator, DOE/CAO needs to be able to identify and evaluate HazMatMgmt technologies in an objective way from the unique perspectives of the various "stakeholders":

- a) for a private contractor (or an external investor) who may be contemplating commercializing a particular DOE-developed HazMatMgmt technology or, once commercialized, may be contemplating "marketing" that technology to a particular site in the US-Mexico border region; or
- b) for a facility owner/operator in the US-Mexico border region who has particular HazMatMgmt problems or may be contemplating contracting for a particular HazMatMgmt technology.

Moreover, to solicit program funding in addition to fees for the above services, DOE/CAO must adequately demonstrate the value to the public or to a particular corporation of participating in the development and operation of such a HazMatMgmt facilitation program in the US-Mexico border region.

Hence, preliminary models have been developed by Golder Associates (under contract to COMPA Industries for DOE/CAO) to evaluate the cost-benefit of: (a) commercializing, marketing or implementing specific HazMatMgmt technologies from either the buyer's or seller's perspective; and (b) developing and operating a HazMatMgmt facilitation program from either the public's or a particular corporation's perspective. These models: (a) are simple and "top-down", based on specified inputs, and can easily be developed in more detail as needed; (b) can be used to determine the optimum combination of decision variables which maximize cost-benefit; and (c) can explicitly incorporate the inherent uncertainties in the input parameters to determine the uncertainty in cost-benefit, and automatically determine the sensitivity of the results. The results of such models provide the basis for achieving consensus amongst the stakeholders and making defensible decisions within and about the HazMatMgmt facilitation program.

INTRODUCTION

As discussed by Scott and Jimenez (ref. 1):

- there are significant hazardous materials management (*HazMatMgmt*) problems in the recently industrialized United States (US)-Mexico border region; and
- there may be significant mutual benefit in commercializing and then using US Department of Energy (DOE) developed technologies to solve some of these problems.

It has been proposed that a specific program may be useful to facilitate commercialization and implementation of more cost-effective *HazMatMgmt* technologies. However, for such a *HazMatMgmt* facilitation program to be successful, the various “stakeholders” (ie., the public, government agencies, corporations, facility owners/operators, developers, contractors, investors, etc.) must choose to participate and collectively provide adequate funding for the program. Logically, a stakeholder will choose to participate (if at all) at the level where the perceived benefit it receives from the program most exceeds its cost to participate. Hence, as a precursor to a programmatic business plan, tools have been developed by Golder Associates (under subcontract to COMPA Industries for DOE/CAO) to evaluate the cost-benefit of participation for each of the stakeholders (ref. 2).

In subsequent sections of this paper:

- current *HazMatMgmt* and the associated problems in the US-Mexico border region are briefly discussed;
- the potential for improving *HazMatMgmt* in the US-Mexico border region is explored;
- a program which has been proposed to facilitate improved *HazMatMgmt* in the US-Mexico border region is presented;
- tools which have been developed for evaluating the cost-benefit of such a program are described; and
- recommendations for continuing development of the program are presented.

HAZARDOUS MATERIALS MANAGEMENT IN THE US-MEXICO BORDER REGION

Current Situation. Currently, there are a large number of facilities (“sites”) in the US-Mexico border region which utilize hazardous materials, with some corporations having more than one site. Such hazardous materials must be transported to each site and stored until used. Although the processes used at each site (eg., in manufacturing) will consume some of these materials, some hazardous wastes are typically produced. Such wastes must be collected and either treated (eg., recycled) or disposed of, which is often expensive and negatively affects the efficiency of the rest of the process. Typically, transportation and disposal of hazardous materials is done through an infrastructure which services multiple sites within an area. Similarly, a corporation with multiple sites may share some activities amongst their sites (eg., centralized waste treatment), or at least use similar processes. Such a flow of hazardous materials is summarized schematically in Figure 1a.

Releases of, or worker exposures to, hazardous materials (including wastes) can occur at any point in the system, but especially from storage or disposal areas. Worker exposures to hazardous materials can result in adverse health effects to those workers, whereas releases of hazardous materials can result in environmental/ecological damage and possibly exposure (and thereby adverse health effects) to the public, possibly at significant indirect costs to the facility owner/operator (eg., bad publicity). Releases, if detected and if they do not quickly dissipate, may require cleanup, typically at significant direct cost and possibly significant additional indirect cost to the facility owner/operator and additional worker risk.

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Hence, the use of hazardous materials, and management of associated wastes, can result in the following adverse consequences, depending on how it is done:

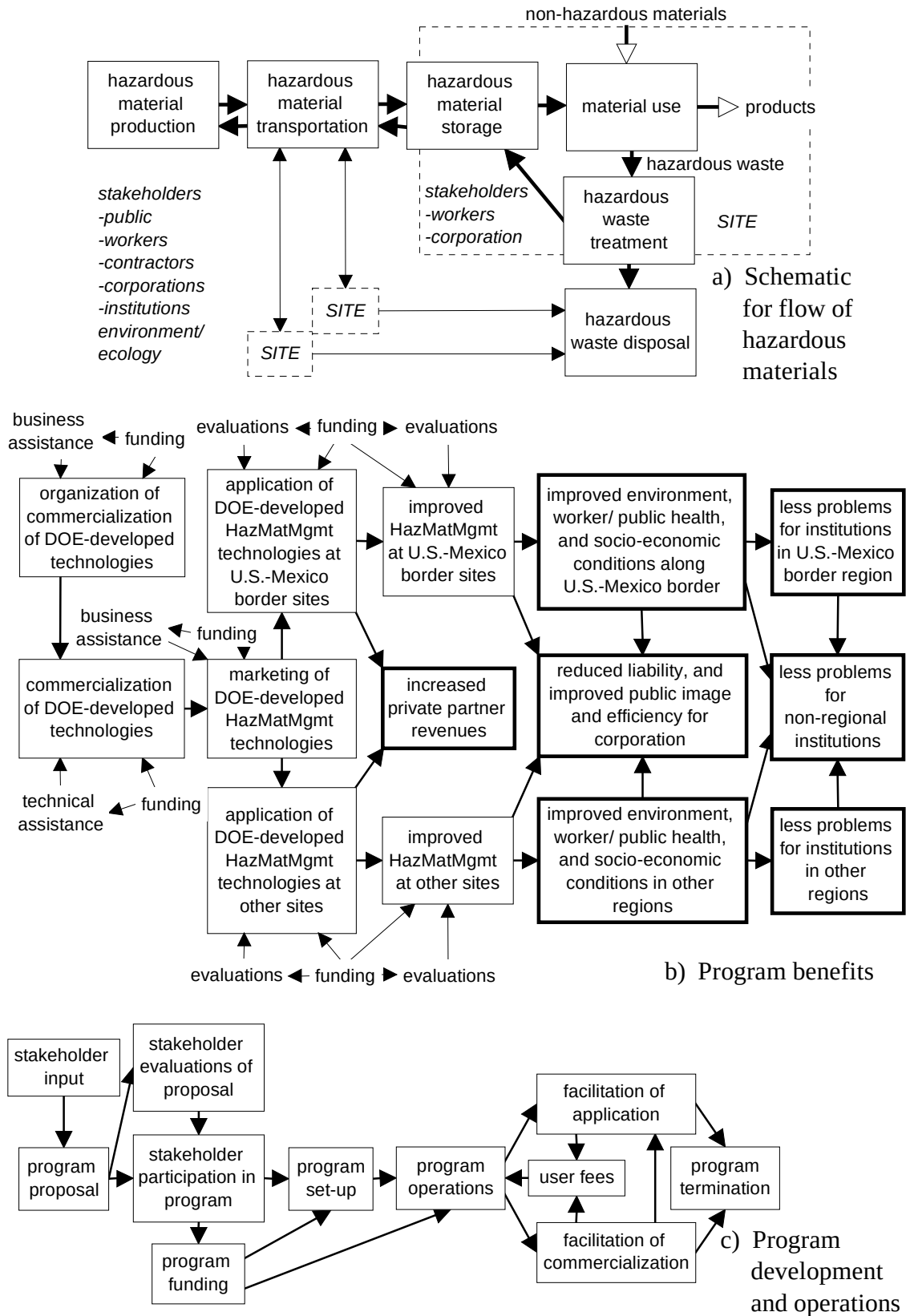


Figure 1. Programmatic Issues

- human health and safety impacts, to workers and to the public;
- environmental and ecological impacts to the region;
- financial impacts to the facility owner/operator, both direct (eg., cleanup, lawsuits, fines, etc.) and indirect (eg., inefficient operations, bad publicity, etc.); and
- socioeconomic impacts to the region, eg., loss of jobs and services due to facility slow- or shut-downs.

Potential Improvements. Improved HazMatMgmt at sites in the US-Mexico border region (or elsewhere for that matter) can clearly result in benefits to the various stakeholders; eg., as summarized by the bold boxes in Figure 1b:

- for the public, improved environment and ecological conditions, health conditions and socio-economic conditions in the area;
- for workers, improved health conditions;
- for facility operators/owners, less liabilities, improved public image and possibly improved operational efficiency;
- for other institutions, fewer problems for government bodies (eg., local jurisdiction), better compliance for regulators, and more accomplishments for external funding agencies.

Improved HazMatMgmt at sites in the US-Mexico border region can result from either or both of the following two key elements: 1) the availability and subsequent application of more cost effective technologies; and/or 2) increased funding for HazMatMgmt. The availability and application of more cost effective technologies will allow more to be done for the same cost (although some investment may first be required), whereas more funds will also allow more to be done.

Technology Investment. The availability of more cost-effective technologies can be achieved, at least in part, through commercialization of selected DOE-developed technologies (ref. 3). Over the years, the DOE and its contractors have developed numerous technologies which, if adequately commercialized, could be applied to various aspects of HazMatMgmt in the US-Mexico border region, with significantly improved consequences (ie., cheaper, safer, faster and/or more effective). These technologies relate to (see Figure 1a): (a) transportation, handling, and storage of hazardous materials; (b) use of hazardous materials in manufacturing processes and treatment of associated hazardous wastes; (c) characterization and monitoring of hazardous materials, especially uncontrolled releases; (d) disposal of hazardous wastes; and (e) remediation of contamination due to uncontrolled releases. Many of the technologies, and their relevant attributes (eg., ownership and development status, applicability and cost-effectiveness, etc.), are currently documented in a DOE data base, ie., *Technology Management System (TMS)*, which is available on the world-wide web at <http://em-52.em.doe.gov/IFD/TMS>.

Successful commercialization of a DOE-developed technology will, in turn, require the following four key elements (see Figure 1b): 1) a private partner; 2) adequate funding; 3) technical expertise; and 4) business expertise. Without any one of these elements (or without a competitive advantage once commercialized), commercialization will fail. In any case, the level of success will be a function of the funding, as well as the technical and business expertise, applied during the commercialization process. Hence, a private partner must be found who: 1) has access to enough funding, technical expertise and business expertise to make commercialization successful; and 2) who perceives that such commercialization will result in a significant return on their investment. Funding, technical expertise and business expertise can be internal, or can be obtained externally (eg., funding through grants or external investors, and expertise through consultants or possibly provided by DOE), possibly facilitated by others. The private partner's perception regarding return on investment will be a function of: 1) what they

perceive the market to be for this technology, both in the US-Mexico border region and elsewhere; 2) the market share they think they can achieve with the technology (ie., its competitive advantage); and 3) the profit margin they think they can achieve when applying the technology. Such evaluations can be conducted internally or by others.

Successful commercialization of a DOE-developed technology with significant competitive advantages may provide substantial benefits to the private partner, eg., increased revenue (Figure 1b). Because of this potential advantage, the process for commercializing DOE-developed technologies must ensure equal opportunity for all contractors, ie., specific criteria (consistent with Federal procurement regulations) should be used by DOE to select private partners.

Technology Application. In addition to simply developing more cost-effective HazMatMgmt technologies, such technologies must be appropriately applied at specific sites to achieve improved HazMatMgmt in the US-Mexico border region (see Figure 1b). This requires a “connection” between the providers and the site owner/operators, ie.:

- The providers need to know how and where to market their technology. For example, marketing by a provider would presumably be funded solely by that provider, based on their perception of the increased market share they can achieve as a function of marketing costs. However, such marketing would be facilitated by market analyses (ie., the conditions at each of the sites and the attributes of the competing technologies).
- The site owner/operators need to know what technologies and providers are available, and how to evaluate them. For example, the choice amongst competing technologies at any site by the facility owner/operator will be based on the perceived cost-benefit of implementing each. Moreover, the appropriate amount of funds for HazMatMgmt at each site can also be determined based on the perceived cost-benefit of implementing the available technologies. Although HazMatMgmt funding at a site would generally be internal, it can possibly be obtained externally (eg., through public grants if deemed to be in the public interest). The site owner/operator’s perception regarding the cost-benefit of implementing a particular technology will be a function of: 1) the reduction in their liabilities they think they will achieve; 2) the net change in operational efficiency they think will occur; and 3) the change in public image they think will occur. The public’s perception regarding the cost-benefit of implementing a particular technology will be a function of: 1) the improved environmental and ecological conditions they think will be achieved; 2) the improved public and worker health conditions they think will result; and 3) the improved socio-economic conditions they think will result. Hence, good decisions among available technologies and on funding would be facilitated by evaluations of their cost-benefit, although this often varies amongst different stakeholders, as discussed below.

Technology Evaluations. Hence, decisions on whether (and if so how) to commercialize a HazMatMgmt technology or whether (and if so the level) to market or implement a HazMatMgmt technology at a specific site all rely on predictions of that technology’s consequences (eg., cost, schedule, safety, performance, etc.), relative to those of other technologies, recognizing the inherent uncertainty in such predictions and the difficulty in quantifying some of them. Typically, when comparing alternatives, tradeoffs amongst consequences must be made because there is no ideal alternative (ie., cheapest and safest and fastest and best) and no common units (eg., monetary terms). Instead, the comparison should be based on “cost-effectiveness”, considering all the consequences, their uncertainties and tradeoffs amongst them. However, tradeoffs may vary amongst the various stakeholders, so that they might not agree on the cost-effectiveness of a technology. For application to a particular site, the stakeholders

might not agree on the most cost-effective technology, so that it must be “negotiated” amongst the stakeholders, with the result not always perceived to be fair by all parties and ending up in litigation.

FACILITATION PROGRAM

Function. It has been proposed that a single, unbiased, credible and qualified organization could facilitate improved HazMatMgmt in the US-Mexico border region (as discussed above) most efficiently, with its effectiveness obviously a function of the funding provided. Such funding could reasonably be provided by those who stand to benefit, ie., corporations with one or more sites in the region, the technology providers, and/or the public in the region.

It has been further proposed that the DOE Carlsbad Area Office (CAO), in partnership with the City of Carlsbad NM and supported by qualified contractors, would be ideal to run this facilitation program, ie., provide effective assistance during commercialization of DOE-developed HazMatMgmt technologies as well as during application at sites along the US-Mexico border (see Figure 1b):

- The DOE/CAO can act as a “broker” for selected HazMatMgmt technologies, ie., identify and contact potential private partners for each DOE-developed technology, provide them with relevant market and funding information, and then negotiate agreements with them as appropriate (consistent with federal regulations), including provision of business and technical expertise if desired. Technical assistance could include R&D as well as training, eg., at existing DOE/CAO facilities in Carlsbad NM, as well as evaluations of the potential competitive advantages of the technology. Business assistance could include identifying potential funding sources for commercialization (ie., investment) or subsequently for application (specifically in the US-Mexico border region), as well as market analysis (ie., potential applications and contacts for those applications, specifically in the US-Mexico border region, and technical and business details which affect the likely revenue, if any, from each).
- The DOE/CAO can also service the public and private corporations in the US-Mexico border region by identifying potentially cost-effective solutions (and qualified providers of such solutions), identifying potential funding sources, and conducting unbiased evaluations (eg., cost-benefit) of various HazMatMgmt alternatives for a site. Such evaluations can be the basis for good decisions on HazMatMgmt and its funding at various sites.

The costs to setup and subsequently operate such a program would have to be covered by some combination of public and private money. In soliciting such funding, it will have to be adequately demonstrated that the overall benefits of the program to each stakeholder (eg., the public or a particular corporation) are likely to substantially exceed the costs to that stakeholder. Such a “win-win” solution should be acceptable to all stakeholders and persuade them to participate. Without such participation by the various stakeholders, the program will not be successful. For example: without private partners, DOE-developed technologies cannot be commercialized; without the cooperation of corporations, no improvements will be made at their sites; and without public acceptance, public funding will be difficult.

Process. As summarized in Figure 1c, development and subsequent operation of the program consists of the following steps:

1. Solicitation of stakeholder issues regarding HazMatMgmt, eg., in a workshop.

2. In response to stakeholder issues as identified in step 1, development and presentation of a proposal to the various stakeholders for DOE/CAO to establish a HazMatMgmt program to: 1) facilitate commercialization of DOE-developed HazMatMgmt technologies; and 2) facilitate application of improved HazMatMgmt at US-Mexico border sites.
3. Evaluation of the proposal resulting from step 2 by the various stakeholders, primarily in terms of the costs and likely benefits of the program to each of them, and presumably consistent with their previously expressed issues in step 1.
4. Determination by each of the stakeholders of whether to participate in the program and, if so, the level of their participation (eg., program funding), presumably based on their perception of the cost-benefit to them as evaluated in step 3. Even though this will have been considered in the development of the proposal, there will be uncertainty in which stakeholders choose to participate and in their level of participation.
5. Acquisition of funds from the participating stakeholders, as negotiated with them in step 4. There will be additional uncertainty in the actual funds collected, as stakeholders possibly change their minds.
6. Set up of the program (ie., acquisition of adequate staff, facilities and equipment, as well as development of necessary procedures and information systems) using a portion of the funds obtained from the participating stakeholders in step 5. The effectiveness of the program will clearly be a function of the funds available to establish the program, which as discussed above is uncertain. Even for a particular funding level, the effectiveness will also be a function of how those funds are used and a function of external events (eg., the general economy), which introduce additional uncertainty.
7. Once established in step 6, operation of the program (ie., facilitating commercialization of DOE-developed technologies and facilitating application of improved HazMatMgmt) using the rest of the funds obtained from the participating stakeholders in step 5 as well as specific user fees. The effectiveness of the program will clearly be a function of the funds available to operate the program and the degree to which the program is used, both of which are uncertain and will be affected by how much the program charges for its services (ie., if the services are too high, no one will use it, whereas if the services are too low, the program will be underfunded and the quality of service will be low, eventually resulting in no one using it). Even for a particular operating funding level and degree to which the program is used, the effectiveness of the program is a function of operational efficiency and a function of external conditions and events (eg., development of better technologies outside the program, or changes in environmental regulations), which introduce additional uncertainty.
8. If operations of the program in step 7 become non-cost-effective (eg., because not enough people are using it, as discussed above, or because the major benefits have already been achieved and only minor benefits which are relatively costly to achieve remain), then termination of the program.

As part of step 1, the DOE/CAO and the City of Carlsbad co-sponsored a forum that was held on August 12-13, 1998 in Carlsbad, New Mexico, which was attended by 132 individuals, including elected federal, state, and city officials and representatives from the US and Mexico, industry representatives, and representatives from several national laboratories.. The forum accomplished the following:

- raised awareness of the growing HazMatMgmt issues, and its impact on public health in particular, in the US-Mexico border region;
- introduced ways to apply the DOE's technologies to improve HazMatMgmt in the US-Mexico

- border region;
- stimulated discussions on the merits of applying specific innovative technologies to the US-Mexico border region's HazMatMgmt needs; and
- developed both a general consensus that a facilitation program (as discussed above) would be useful and an outline for a preliminary path forward to accomplish that program (ie., the remaining steps 2-8).

PROGRAM EVALUATION TOOLS

Overview. A critical part of the proposed HazMatMgmt facilitation program in the US-Mexico border region is the ability to objectively evaluate HazMatMgmt options, as well as (at a higher level) the program itself. Hence, several simple, related, top-down models have been developed by Golder Associates (under subcontract to COMPA Industries for DOE/CAO) (Scott et al, 1998):

- The individual technology development model, as summarized schematically in Figure 2a, determines the likely return on investment for a potential private partner, as well as for an external investor (if any), in developing a particular HazMatMgmt technology. It combines estimates of the potential market (revenues) for the technology as a function of its competitive advantages, which in turn is a function of development funding. It can be used to determine the optimal development strategy (in terms of internal and external development funding) for a particular HazMatMgmt technology.
- The site implementation model, as summarized schematically in Figures 2b and 2c, determines the likely cost-benefit of a particular HazMatMgmt technology at a specified site, either for implementing it at the site (from the facility owner/operator's perspective, Figure 2b) or for marketing it to the site (from the contractor's perspective, Figure 2c). It combines tradeoffs and estimates of the consequences of implementing or marketing that technology at a particular site as a function of the level adopted (and thus costs), a relationship which in turn is expressed as a function of the specific site conditions. It can be used to compare technologies for implementation at a site, or to compare sites for marketing a technology, as well as to determine the optimal level of either.
- The program model, as summarized schematically in Figure 2d, determines the likely cost-benefit of the improved HazMatMgmt program from both the public's perspective, as well as from each corporation's perspective. It combines tradeoffs and estimates of the consequences of improved HazMatMgmt for all the sites of interest, which in turn is a function of the development of more cost-effective techniques and of more funds for implementation. It can be used to determine the optimal HazMatMgmt strategy for the region (in terms of public and corporate development funding and implementation funding).

In each of the models described above, a measure of cost-benefit from a particular perspective is expressed as an explicit function of various input parameters (including decision variables), as will be subsequently discussed. In each case, these algorithms have been implemented in an EXCEL spreadsheet, using interactive charts to specify some parametric relationships. The optimum combination of decision variables which achieves the maximum cost-benefit measure while satisfying specified constraints can be determined (by constrained optimization using the EXCEL SOLVER command).

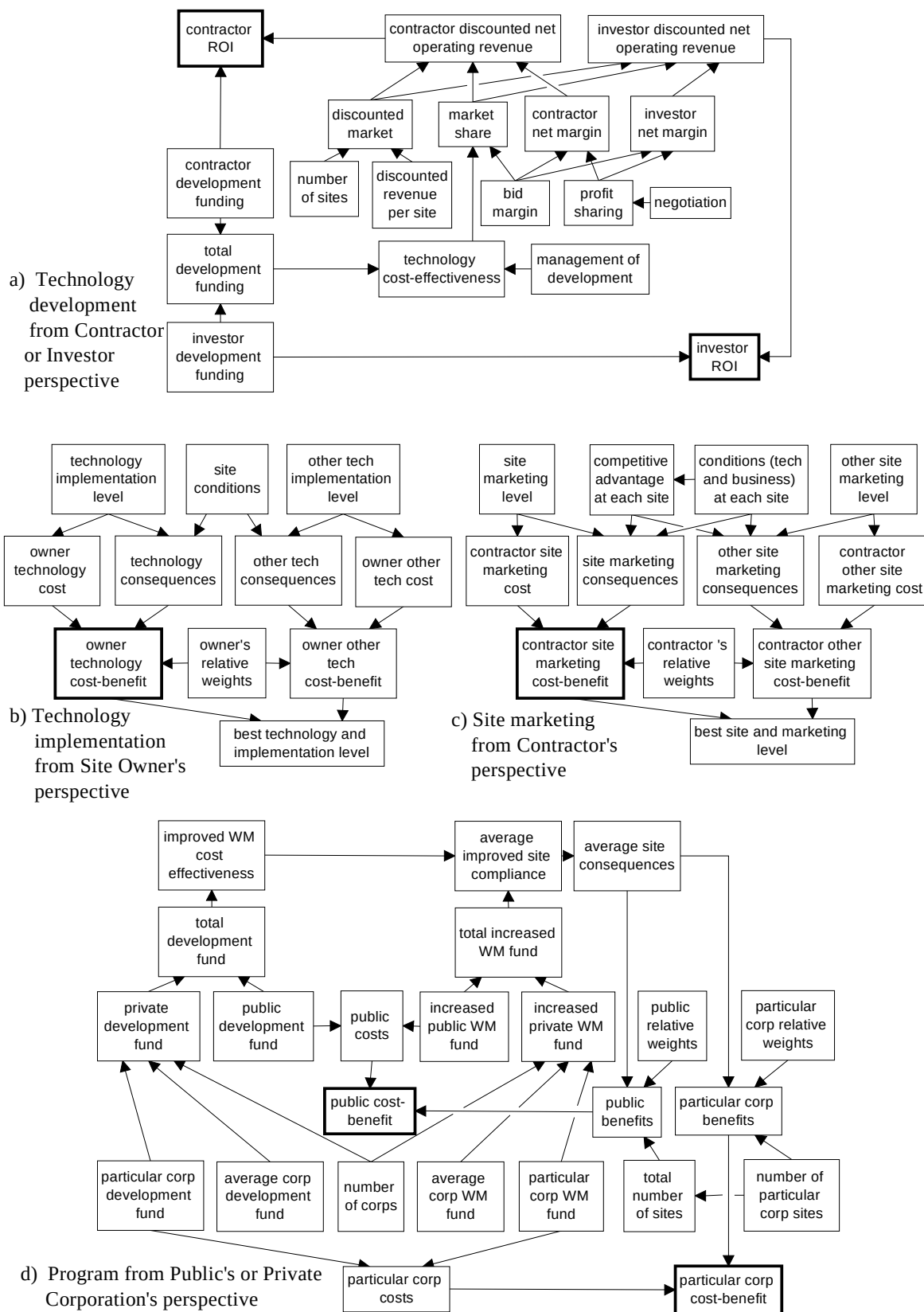


Figure 2. Logic Incorporated in Cost-Benefit Models

Although not currently done, these models could be explicitly linked, using common inputs (eg., site and technology data bases) with the results of one model feeding another, to ensure consistency across the various levels of detail of interest (ie., individual technologies or sites, and sets of sites and, in some cases, technologies). For example, submodels could be developed for each site separately, and the results could be aggregated among selected sites in the region (for each corporation) or among all sites in the region (for the public).

As discussed above, these models rely on various inputs, as well as on some assumptions (eg., the sites are sufficiently separated and independent so that the consequences for different sites are additive). The accuracy of the model results depends on the accuracy of these inputs and assumptions. Although the assumptions may be reasonable, there may be significant uncertainty in the inputs due to a lack of direct information (eg., measurements) on them or due to their speculative nature. Hence, the inputs might be best assessed based on defensibly elicited subjective assessments of experts in the relevant field, consistent with all available information:

- Initially, this might be done directly at a broad level of detail (eg., in terms of averages over all the sites being considered) and in terms of single “expected” (probability weighted average) values. The results would be in terms of single expected values of the cost-benefit measure, with the uncertainty in those values not quantified.
- Later, it could be done more accurately by doing it in more detail (eg., for each individual site) and in terms of “probability distributions” (which express the uncertainty in the set of input parameter values). The results (developed by Monte Carlo simulation using the EXCEL @RISK add-in) would be in terms of probability distributions, which quantify the uncertainty in the value of the cost-benefit measure and can be used to determine the probability of exceeding specified thresholds. At the same time, the sensitivity in the results could also be quantified.

Although not perfect, this may be the best that can be done in a reasonable time frame and with reasonable resources, and the results may be sufficiently accurate to make good, defensible decisions.

Individual Technology Development Model. A model for a potential private partner to determine the optimal amount (if any) of their internal funding (ie., investment cost) can be expressed in terms of maximizing the contractor’s “return on investment (ROI)”, which in turn can be expressed simply as follows:

$$\begin{aligned} \text{contractor's ROI} &= (\text{revenue} - \text{cost})/\text{cost} \\ &= \{(\text{market} * \text{market share} * \text{net margin}) - \text{investment cost}\} / \text{investment cost} \end{aligned} \quad (\text{Eqn 1})$$

where

market is the total potential revenue (discounted to NPV), which in turn equals the total number of potential sites times the average revenue per site (discounted for when in the future they will occur);

market share is expressed as an explicit function of the technology’s *cost-effectiveness* (relative to other technologies) and the contractor’s *bid margin*;

cost-effectiveness combines the technology’s various attributes (eg., cost, rate, performance, reliability, etc.) into one measure (eg., a score) which can be compared with those of other technologies, and is expressed as an explicit function of *total development funding*,

which in turn equals *external development funding* plus *internal development funding* (investment cost), and how well development is managed; and *net margin* is expressed as an explicit function of the contractor's *bid margin* and the amount of *external development funding* (ie., any profits would have to be shared with other investors, depending on the level of their investment, which would have to be negotiated).

Similarly, a model for a potential investor to determine their optimal amount (if any) of external funding for development can be expressed in terms of maximizing the investor's "ROI", which in turn can be expressed as follows:

$$\begin{aligned} \text{investor's ROI} &= (\text{revenue} - \text{cost})/\text{cost} \\ &= \{(\text{market} * \text{market share} * \{\text{bid margin} - \text{net margin}\}) \\ &\quad - \text{external development funding}\}/\text{external development funding} \end{aligned} \quad (\text{Eqn 2})$$

Hypothetical input parameters (both expected values and probability distributions), as well as constraints on the decision variables, are shown in the spreadsheet depicted in Figure 3a. Also as shown, constrained optimization was done for this hypothetical example to identify the optimum combination of bid margin, internal development funding and external development funding to maximize the contractor's ROI; alternatively, the investor's ROI could have been maximized. For this optimum set of decision variables, the uncertainty and sensitivity of the investor's ROI was determined, as shown in Figures 3b and 3c.

Site Implementation Model. A model for a facility owner/operator to evaluate the implementation of specific HazMatMgmt activities at a particular site can be expressed in terms of maximum cost-benefit, where "benefits" from the facility owner/operator's perspective can be expressed as follows:

$$\text{owner benefits} = \sum_i W_i C_i \quad (\text{Eqn 3})$$

where

C_i is the set of the various consequences i of the activity, including

- their reduced liabilities,
- their improved operational efficiency, and
- their improved public image; and

W_i is the set of relative weights for each of the different types of consequences i , which express the tradeoffs (from the facility owner/operator's perspective) amongst those consequences

The relative weights for each type of consequence depends on how each of the consequences are defined. The relative weight for each consequence could then be defined, independently from the relative weights for the other types of consequences but in comparable terms, as the amount of money the facility owner/operator would be willing to spend to increase the consequence by one unit.

The consequences of each type for a particular activity at a specific site are, in turn, expressed as an explicit function of the various site conditions and the level of implementation, which in turn also affects the costs for implementing that activity.

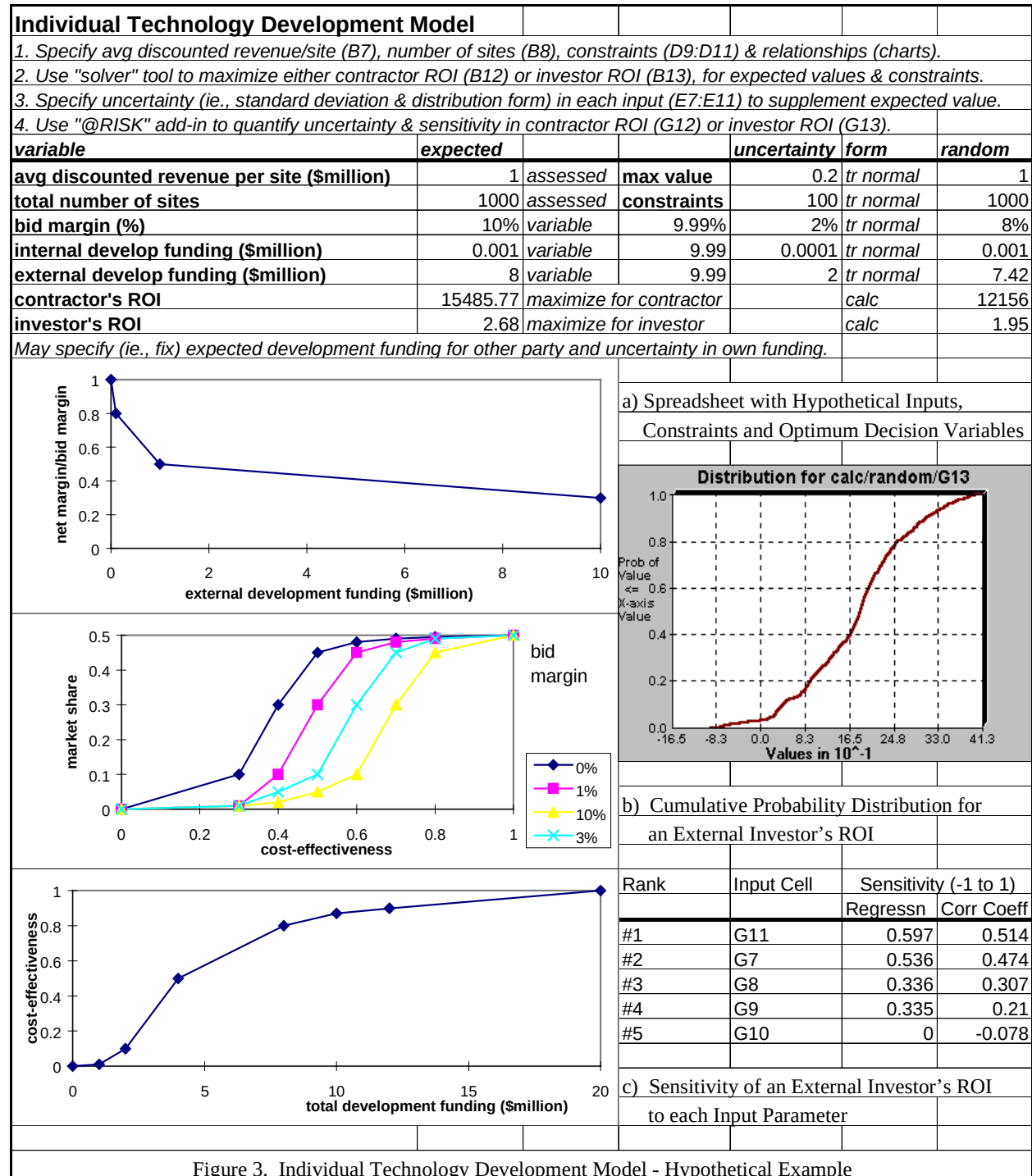


Figure 3. Individual Technology Development Model - Hypothetical Example

Cost-benefit for each HazMatMgmt activity from the facility owner/operator's perspective can thus be determined by comparing their costs to their *benefits*, similar to ROI:

$$\text{owner cost-benefit} = (\text{owner benefits} - \text{owner cost}) / \text{owner cost} \quad (\text{Eqn 4})$$

A model for a contractor to evaluate sites for marketing a specific HazMatMgmt activity is essentially the same as for a facility owner/operator evaluating implementation, as presented above, except:

- the set of beneficial consequences of marketing a site include increased revenue from that site, and increased market share (revenue from other sites);
- these consequences are a function of the marketing level (which determines marketing cost) as well as site conditions; and
- the relative weights and costs (as well as benefits) are from that contractor's perspective.

Although not shown here (see ref. 2), a spreadsheet similar to that shown in Figure 3a has been developed and successfully exercised in a similar way with a hypothetical example.

Program Model. A model for the public to evaluate an improved HazMatMgmt program as a whole can be expressed in terms of maximum cost-benefit, where "benefits" from the public's perspective can be expressed as follows:

$$\text{public benefits} = \sum_i W_i C_i \quad (\text{Eqn 5})$$

where

C_i is the set of the various consequences i of the program, including

- improved environmental/ecological conditions,
- improved public health conditions,
- improved worker health conditions, and
- improved socio-economic conditions; and

W_i is the set of relative weights for each of the different types of program consequences i , which express the tradeoffs (from the public's perspective) amongst those consequences and are derived in a similar way as discussed with respect to Eqn 3.

A meaningful "measure" of improved health conditions might be the increased number of healthy years experienced by the population, which would combine the reduced number of fatalities and their age, and the reduced number and severity of injuries, sickness and disease.

The program consequences of each type can, in turn, be determined as simply the summation of those consequences for all sites affected by the program, assuming that the consequences are independent and additive among sites:

$$\begin{aligned} C_i &= \sum_j C_{ij} \\ &= N * m[C_{ij}] \end{aligned} \quad (\text{Eqn 6})$$

where

C_{ij} is consequence i for each site j ;

$m[C_{ij}]$ is the average consequence i among all N sites; and

N is the total number of sites j .

The average consequence of each type among all sites is, in turn, a function of the average improvement in environmental compliance among all sites, where environmental compliance might be expressed relative to a standard. The average improvement in environmental compliance among all sites (eg., from 50% to 75%) would increase because action is taken at more sites (either because more HazMatMgmt funding is available or because equally effective HazMatMgmt technologies are cheaper) or because the

action taken at some sites is more effective (either because more HazMatMgmt funding is available or because equally expensive HazMatMgmt technologies are more effective). Hence, the average improvement in environmental compliance among all sites would be a function of increased HazMatMgmt funding and the improved cost-effectiveness of the set of commercially available HazMatMgmt technologies, which in turn is a function of the effort associated with commercializing the various HazMatMgmt technologies. Ultimately, therefore, the average consequence of each type among all sites is a function of increased HazMatMgmt funding and the effort associated with commercializing the HazMatMgmt technologies. Finally, these two different funds which determine the benefits can be divided into public and private.

Cost-benefit from the public's perspective can thus be determined by comparing the public's *costs* to their *benefits*, similar to ROI:

$$\text{public cost-benefit} = (\text{public benefits} - \text{public cost}) / \text{public cost} \quad (\text{Eqn 7})$$

where

$$\text{public cost} = \text{public development fund} + \text{incr public HazMatMgmt fund} \quad (\text{Eqn 8})$$

A model for a particular corporation to evaluate an improved HazMatMgmt program is essentially the same as for the public, as presented above, except:

- the set of beneficial consequences of the program include their reduced liabilities, improved operational efficiency, and improved public image; and
- the relative weights and costs (as well as benefits) are from the corporation's perspective.

For a particular corporation, their benefits derive from the consequences summed only over that corporation's sites (ie., a much smaller number of sites), again assuming that the consequences are independent and additive among sites. Similarly, however, their costs consist only of their *corporate development fund* plus their *increased corporate HazMatMgmt fund*, which is only a small part of the total private funding. Hence, a particular corporation is only concerned with a portion of the overall system, whereas the system is comprised of a set of corporations:

$$\text{total number of sites (N)} = \text{number_of_corp_sites} \quad (\text{Eqn 9})$$

$$\text{private development fund} = \text{corp_development_fund} \quad (\text{Eqn 10})$$

$$\text{incr private HazMatMgmt fund} = \text{corp_HazMatMgmt_fund} \quad (\text{Eqn 11})$$

Although not shown here (see ref. 2), a spreadsheet similar to that shown in Figure 3a has been developed and successfully exercised in a similar way with a hypothetical example.

CONCLUSIONS

A program for facilitating commercialization of DOE-developed HazMatMgmt technologies and for facilitating improved HazMatMgmt specifically to US-Mexico border region industrial sites may be mutually beneficial to all stakeholders, including the public, private business (either corporations with facilities in the region, HazMatMgmt contractors or investors) and institutions (such as regulators). The benefits of such a program (eg., improved HazMatMgmt technologies) may extend far beyond the US-

Mexico border region. However, for such a program to succeed, various functions (eg., both technical and business related) must be performed, which in turn requires adequate funding. It is proposed that DOE/CAO, which is particularly well positioned, perform many of these functions and be funded by the various beneficiaries in an equitable manner.

As the basis for making good, defensible decisions within the program (eg., regarding commercialization of specific DOE-developed HazMatMgmt technologies or regarding marketing or application of specific HazMatMgmt technologies at a site), it is necessary that the possible consequences of such decisions be appropriately and definitively evaluated (eg., expressed in terms of cost-benefit for the various stakeholders). Simple, top-down models have thus been developed to adequately conduct these evaluations, based on specified inputs. Constrained optimization can be conducted using these models to determine the optimum set of decision variables, maximizing the cost-benefit measure. However, there is typically little direct information available on many of these inputs, leading to significant uncertainties and the need to base their assessments on expert judgment. Such uncertainties can be explicitly considered in the evaluations and expert judgment can be defensibly elicited using specific techniques.

The various evaluations could be enhanced by explicitly linking the models together and by developing separate data bases for site and HazMatMgmt technology characteristics, which would be used to provide much of the input required. Portions of such data bases have previously been developed, but would need to be modified, updated, and extended.

RECOMMENDATIONS

It is recommended that the stakeholders (ie., DOE HazMatMgmt technology developers, private partners/investors, US-Mexico border region industrial facility owner/operators, representatives of the public potentially affected by US-Mexico border region industrial facilities, etc.) get together in additional forums to discuss their issues (objectives, alternatives, and evaluation approaches, including specific models). If the stakeholders decide to proceed, the following steps should then be taken:

- 1) identify alternative HazMatMgmt program strategies;
- 2) finalize the evaluation models presented herein, possibly linking them explicitly;
- 3) develop and maintain a data base of the model inputs (regarding site conditions and HazMatMgmt technology attributes), building on previous work, to facilitate use of the models in conducting consistent evaluations;
- 4) conduct workshops to elicit model inputs from qualified experts, and input to the data base;
- 5) evaluate alternative HazMatMgmt program strategies at various levels of detail and from different perspectives; and
- 6) implement the HazMatMgmt program strategy which is best from all perspectives.

The program should be periodically reviewed, identifying possible program modifications and evaluating them in the same way, ie., focusing on the ultimate consequences.

REFERENCES

1. G. Scott and R. Jimenez, "Development of a Bi-National Strategy for Leveraging the US Technology Base to Improve Hazardous Waste Management in the US-Mexico Border Region," concept paper, May (1998).
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