

Development of Expert System for Mitigating Occupational Health Impact of Pesticides

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ACKNOWLEDGEMENT

Several persons have contributed to realizing the project herein described. We would like to give our gratitude to our classmates for providing input to the project. We would also like to acknowledge the contribution of our supervisors, Dr. Raghavan- for his passion and commitment to developing agricultural sustainability in India and to Dr. Clark- for his guidance and expertise through the project.

EXECUTIVE SUMMARY

Pesticides, as compounds designed to annihilate target organisms, are by their very nature noxious substances for which exposure must be limited and adverse effects mitigated. Pesticides pose discernable impact to both human and environmental health. While regulatory structures exist in developed nations, the frameworks necessary to govern their use and mitigate the associated detriment in developing nations may not exist or may not be implemented in practical terms. Insufficient resources in developing nations may hinder best management practices of pesticides. This disparity is particularly significant given that agricultural workers in developing nations comprise the largest percentage of the global agricultural workforce. When opportunities to implement mitigation strategies exist, it is thus critical that they optimize the benefit to workers. The following report describes the development of an expert system software tool designed to characterize the risk associated with pesticide usage and to facilitate the choice of management strategies that best mitigate consequences for occupational health. The report describes the design principles and methodology used in the development of the expert tool. A framework for project implementation is also discussed.

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INTRODUCTION

The intensive use of pesticides has been one of the factors contributing to high crop yields and lower commodity prices. Farmers employing pesticides have benefited from roughly a four-fold return on initial pesticide investment due to increased yields (Kellogg et al., 2000). Pesticides however, as compounds designed to annihilate target organisms, are by their very nature, noxious substances for which exposure must be limited and adverse effects mitigated. Pesticides have been identified to contribute to a multitude of human health ailments, both acute (abdominal pain, headaches, dizziness, nausea, skin irritations etc...) and chronic (repertory illness, cancer, memory disorders, birth defects, kidney disorders, and neurological defects) in nature (Michael et al., 2004). The routine and direct nature of occupational exposure renders it the most problematic of human exposure opportunities. Relevantly, results from field studies have identified that pesticide use has a negative effect on farmer health and that farmer health has a positive effect on productivity (Antle & Pingali, 1994). Thus, unless the integrity of farmer's health is protected, the pest management technologies introduced to ameliorate crop productivity and financial stability may instead compromise the efficiency of agricultural and social systems. In addition to the discernable impacts pesticides impose upon biological organisms and the environment they occupy, pesticides pose unique risks to farmers- particularly the financially burdening nature of these technologies, as well as the consequences they imply on future pest levels (Benbrook et al., 2002). While regulatory structures exist in developed nations, the frameworks necessary to govern their use and mitigate the associated detriment in developing nations may not exist or may not be implemented in practical terms. The adoption of best management practices may be further hindered by inadequate access to knowledgebase, educational and human-expert resources- as limited by factors including remote locality, constraints of time and monetary resources and inexistent support infrastructures. This disparity is particularly significant given that agricultural workers in developing nations comprise the largest percentage of the global agricultural workforce. When opportunities to implement mitigation strategies exist, it is thus critical that they optimize the benefit to workers.

PROBLEM STATEMENT

Navigating the complex socio-economic and technical challenges of optimizing the benefit of pesticides on crop productivity, while mitigating exposure consequences, inherently requires expertise in a broad spectrum of disciplines. Furthermore, when amelioration opportunities exist, tools are necessary to quantify the potential significance of these improvements. Expert-systems are computational tools designed to facilitate decision making by clarifying uncertainties that would otherwise require the contribution of various human experts and knowledgebases. The project herein described aims to characterize risk and facilitate the decision of risk mitigation regimes to protect occupational health. The design integrates findings of research that remain otherwise largely inaccessible to the public, including: toxicological profiles, pesticide risk indicators and mitigation efficacy studies found in scientific literature and technical reports. The objective of the project is thus to develop a user friendly computational software tool to characterize the risk associated with pesticide usage for farm specific parameters, and from this data, facilitates the choice pesticide application strategies and regimes that most effectively mitigate consequences for human health.

EXPECTED OUTCOMES

The following objectives were defined for the development of the expert-system:

Immediate:

- To develop a system that integrates knowledge of pesticide toxicology, risk assessment and farm specific parameters to characterize the occupational health risk
 - To output a clearly displayed diagnostic of risk for current pesticides practices at the farm level
- To optimize the mitigation of occupational risk reduction
 - To review all relevant knowledge and scientific literature on the best systems to mitigate occupational health risk by engineering controls, the use of personal protective equipment (PPE) and alternative biological agricultural systems

- To identify important variables which govern occupational exposure to pesticides such that they be considered within the context of risk reduction

Long Term:

- To behave as an educational resource for public health policy
- To develop a tool that can facilitate decision making for the farmer and other land managers in order to mitigate the consequences pesticides impose on workers occupationally
- To promote best management practices of pesticides by encouraging pest management practices that mitigate risk

BACKGROUND INFORMATION

SCOPE

While the methodology herein described is pertinent irrespective of locality, to facilitate the simplicity of the project, the scope is limited to the context of cotton and wheat production in the Punjab state of India. Nevertheless, the methodology can readily be adapted to broaden the context of application for other geographic locations and cropping systems.



Figure 1 Map of Punjab India (<http://www.all-indiatravel.com/india-map/ind-map-3.gif>)

AGRICULTURE

Punjab, India has often been called the bread and rice bowl of India due to its high production of wheat and rice grains. An area known for its involvement in the start of the Green Revolution, the state is known for its large agricultural sector. In addition, agriculture has been well documented within this state historically due to government initiatives. Agriculture is split between two seasons, the winter Kharif and the spring Rabi season. Most farmers in Punjab alternate between wheat and rice or wheat and cotton within these seasons.

Agriculture within the region was marked by a shift from organic methods of farming to more intensive methods. This shift was due to the introduction, during the Green Revolution, of genetically modified varieties of crops such as wheat and rice and to improved and wider use of groundwater irrigation practices. The shift also brought on the rapid increase of crop yields within the region, helping to satisfy increasing food demands brought on by a growing population. As such, Punjab has become a powerhouse of grain production.

However, within the past decade, issues associated with the unsustainability and adverse effects of intensive farming practices have come into the forefront. The new grain varieties require substantial inputs of resources such as fertilizer and pesticides. In addition, irrigation practices are under scrutiny as the water table drops at a rate of around 30 feet per year.

PESTICIDE USAGE

Punjab is the largest user of pesticides in India (Figure 2). Intensive agricultural practices were encouraged by the Indian government following the Green Revolution due to the improvement in food security. Pesticides are readily available and government policy has yet to set affective policy regarding their proper application. A prominent issue with pesticide use includes a lack of knowledge by farmers of proper pesticide management practices. Due to the hot climate, pesticide applicators are less likely to wear the proper protective equipment for spraying the fields. Often the application method is inefficient and outdated equipment is used. Farmers will spray pesticides on their fields in much larger amounts than necessary, as well as more times than necessary throughout the cropping season. For example, farmers have been known in Punjab to spread pesticides as many as 20 times during the season, where the recommendation may be two times.

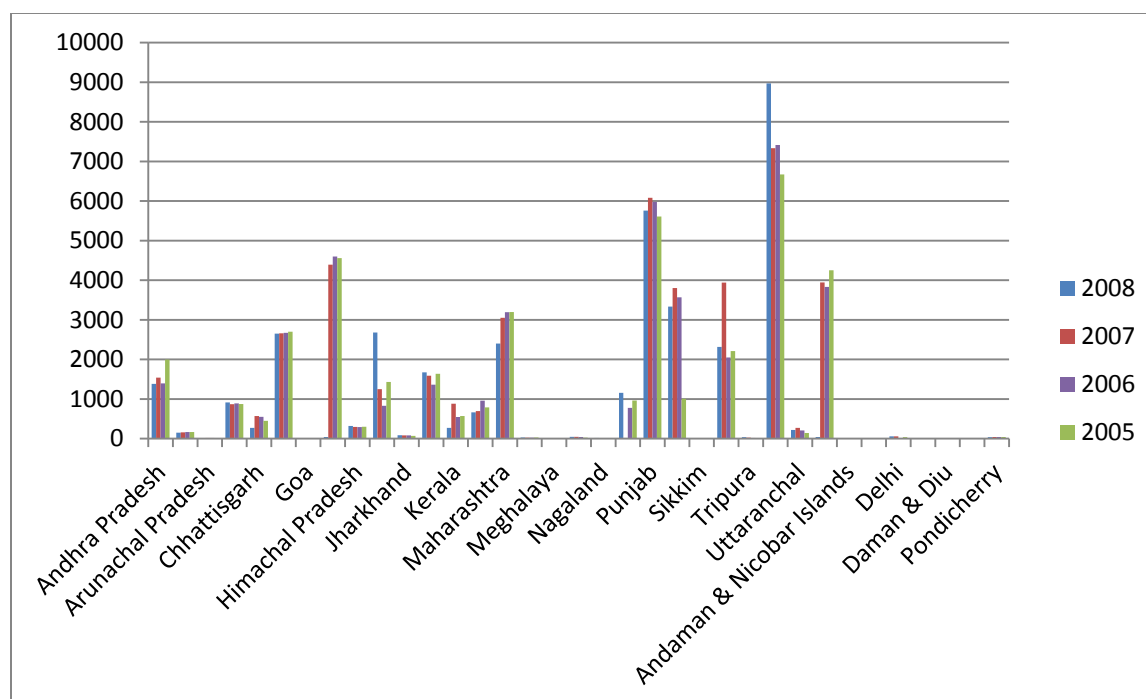


Figure 2 State-wise Consumption of Pesticides in MT (Indiastat, 2009)

Recently, there has been increased media attention regarding the possible link between pesticides and adverse health effects. This is due to a number of studies that have been conducted linking villages with heavy pesticide use with higher rates of cancer and other chronic health issues.

DEFINING OCCUPATIONAL ACTIVITIES

Occupational tasks identified to introduce pesticide exposure opportunities include: mixing loading, application, flagging, harvesting and various other activities such as cleaning equipment (Garreyn, 2003). Pesticide operators- those who mix, load and apply pesticides- have been characterized as the highest risk group for adverse potential (Garreyn, 2003). It is their exposure that has been most extensively documented in the literature and accordingly the scope of the project is limited to mitigating the nature of their exposure opportunities. It has been well documented that the most important route of operator exposure involves dermal absorption- although inhalation and ingestion have also been identified as important exposure routes (Krieger, 2001).

The sequence of handling operations constituting the occupational work day of pesticide operators, is summarized in **Figure-1**. While the figure describes the sequence relevant to tractor-mounted liquid-application, application with handheld equipment follows a likewise sequence- differing only in the respect that dilution of the concentrate may not necessarily be relevant for each replenishment of the sprayer tank.

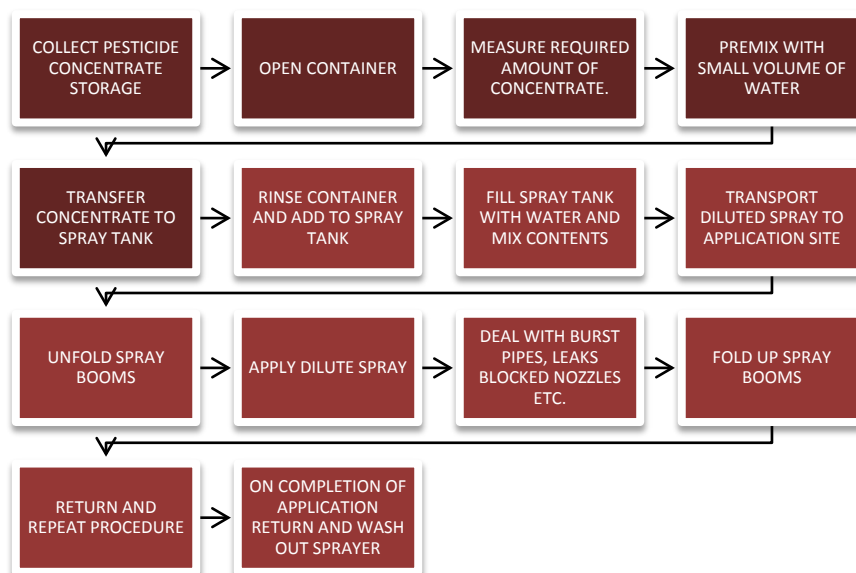


Figure 3 Sequence of Procedures during Spray Application - Adapted from PSD-POEM (2003)

MIXING AND LOADING

Mixing and loading operations constitute applicator activities in which operator exposure to pesticide concentrate exists (designated above in the deep red coloration). Exposure during mixing depends on the concentration of the active ingredients in the product, the number of dilutions and the nature of the formulation (NAIS, 2000). The severity of exposure according to formulation type is described in the following table:

Table 1, Exposure According to Nature of Formulation- Adapted from NAIS, 2000

Low Exposure	High Exposure
<ul style="list-style-type: none"> • Ready to use products • Gels • Granules • Water soluble tables • Formulations from water soluble bags 	<ul style="list-style-type: none"> • Emulsions • Powders • Suspensions • Other soluble concentrates

Handling pesticide concentrates during mixing and loading operations constitutes the most significant skin contamination opportunity identified in the literature (POEM, 2003). This exposure is typically incurred by absorption via the hands.

Time also constitutes an important factor in defining the magnitude of exposure. The time required to complete the aforescribed operations using tractor spray technique is determined by a number of factors including (Matthews, 1979):

- Size of the spray tank
- Bottom width
- Application rate
- Distance between filling point and application site

APPLICATION

Exposure during application depends on parameters including the concentration of the active ingredients in the applied product, the application rate, the spray area and most significantly, the application method (NAIS, 2000). Multiple techniques are available for the application of pesticides to target organisms. The nature of the spray equipment can be summarized as liquid sprays, dry products and others. Amongst these, liquid spray techniques constitute the most frequently employed application strategy. Liquid spray techniques may be further categorized according to: a) tractor operated sprayers- in with both upwards and downwards spray orientations exist, b) handheld sprayers and finally, c) aerial sprayers. Aerial spray applications are not addressed within the scope of this report.

Table 2, Summary of Liquid Spray Equipment- Adapted from PSD-POEM (2003)

Tractor Operator	Handheld Equipment
• Hydraulic boom sprayer	• Single nozzle hydraulic sprayer
• Hydraulic air assisted sprayer	• Hydraulic knapsack sprayer
• Rotary disk boom sprayer	• Hydraulic charged sprayer
• Rotary disk air assisted sprayer	• Single disk drift sprayer

- **Rotary disk drift sprayer**

- **Single disk low level sprayer**

For tractor mounted spray applications, it has been estimated that the handling of concentrate occupies a total of roughly one hour of the working day (POEM, 2003). The remaining operations, designated with the lighter coloration of red, constitute worker interaction with dilute spray. These activities have been estimated to consume a total of roughly nine hours per work day (POEM, 2003). The most significant route of occupational exposure during tractor operations is manifested through the dermal exposure of the hands (Lloyd, G. 1985).

Similarly, for handheld spray applications, the spray operation time is unlikely to consume more than six hours. With consideration however of continuous exposures consequential to matters of contaminated clothing, the exposure time for handheld sprayers is estimated to be roughly nine hours daily. The application regime can be further characterized according to the volume of spray being applied. The spray volumes delivered can vary from less than 5 liters per hectare - Ultra Low Volume to more than 1000 liters per hectare- High Volume (POEM, 2003).

METHODOLOGY OF DEVELOPMENT

A methodology is presented for the development of the expert system software tool. The design criteria, as well as the methodologies for computing risk and integrating risk mitigating of risk within the computational framework are described.

DESIGN CRITERIA

To best meet the objectives previously defined, the following criterion has been established. The expert-system program should abide to the following:

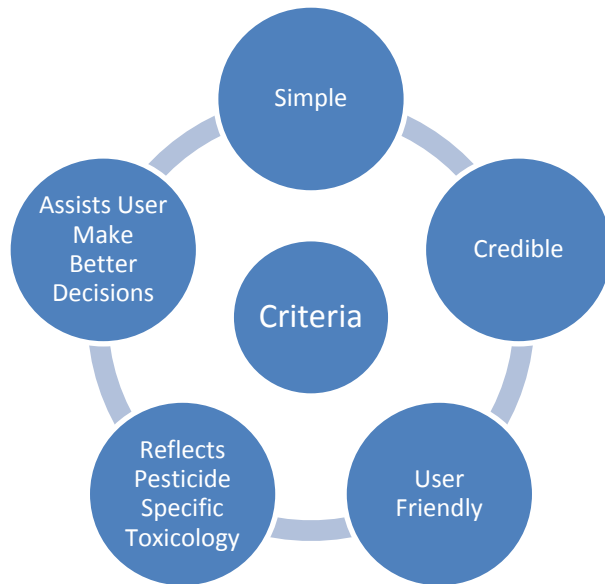


Figure 4 Design Criteria

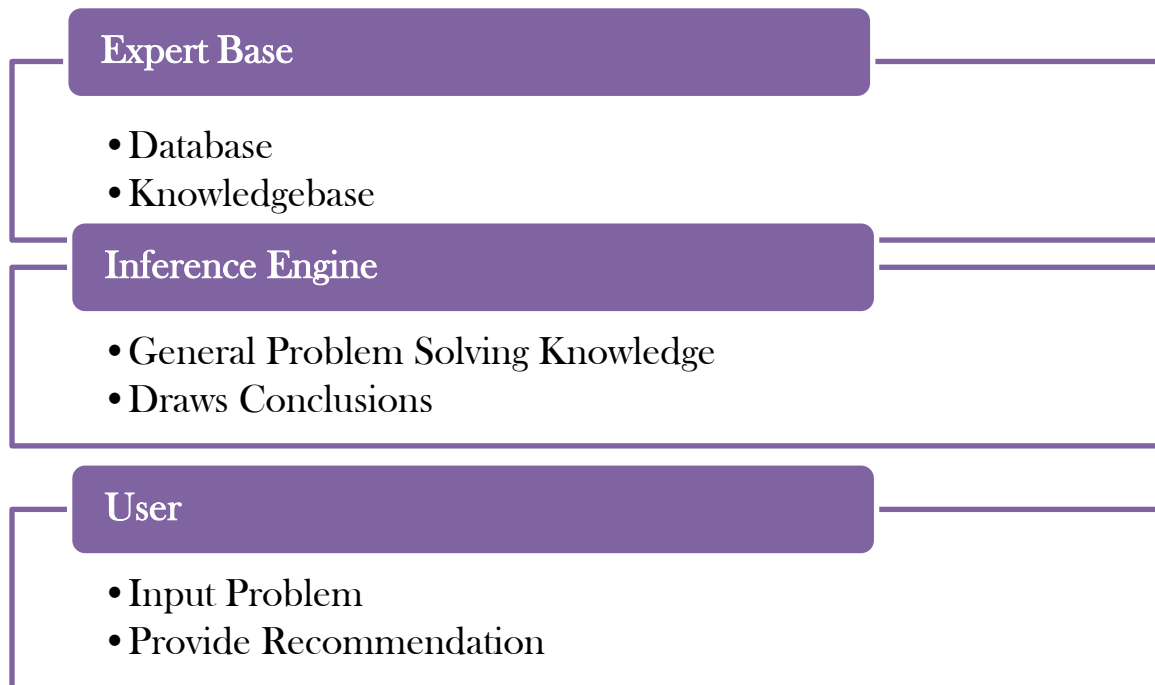
To satisfy the above-described criteria, the following objectives are described:

- **Simplicity:**
 - Provide a graphical user interface with which the user can interact such that the user needn't interact with the computations
 - Given the complex nature of human-environment interactions, a simplified representation of reality adapted to assist in decision making
- **Ease of use**
 - Provide a graphical user interface with which the user can interact
 - Minimize opportunities for ambiguity
- **Credibility:**
 - Based on reliable data and results from scientific literature
 - Based on reasonable assumption
- **Assist the pesticide user in making more appropriate choices:**
 - Promotes the protection of human health and environmental sustainability

- **Reflects pesticide specific toxicology**
 - Acute and chronic toxicity criteria as well as bioaccumulation potential
 - Application techniques and amount of pesticide used
 - Pesticides environmental persistence and potential for bioaccumulation

EXPERT SYSTEM

An expert system compiles and utilizes an expert base of information to find a solution to a pertinent problem and provides it in an easily accessible and efficient manner to a user. The three tiers of an expert system are seen in the figure below.



PROGRAMMING PLATFORM

Criteria influencing the selection of the most appropriate software development platform include:



Figure 5 Criteria for Programming Platform

The programming platform utilized in the development of the risk quantifying software is MATLAB. MATLAB is a high level language for technical computing. Its computing capacity exceeds that of typical programming languages including C++. In addition, it has a built in platform for creating user interfaces called Graphical User Interface Development Environment (GUIDE) (seen in Figure 6 below). This platform works by allowing the user to lay out a graphical user interface (GUI) visually rather than programmatically, easing the creation of the GUI. Various visual objects are available as tools including buttons, dropdown menus, check boxes, static text and editable text boxes. After the creation of the visual layout, a script is generated automatically with functions for the present objects. This script is connected with the previously created layout figure and when the program is run, will produce a working GUI from which user inputs can be recorded and utilized.

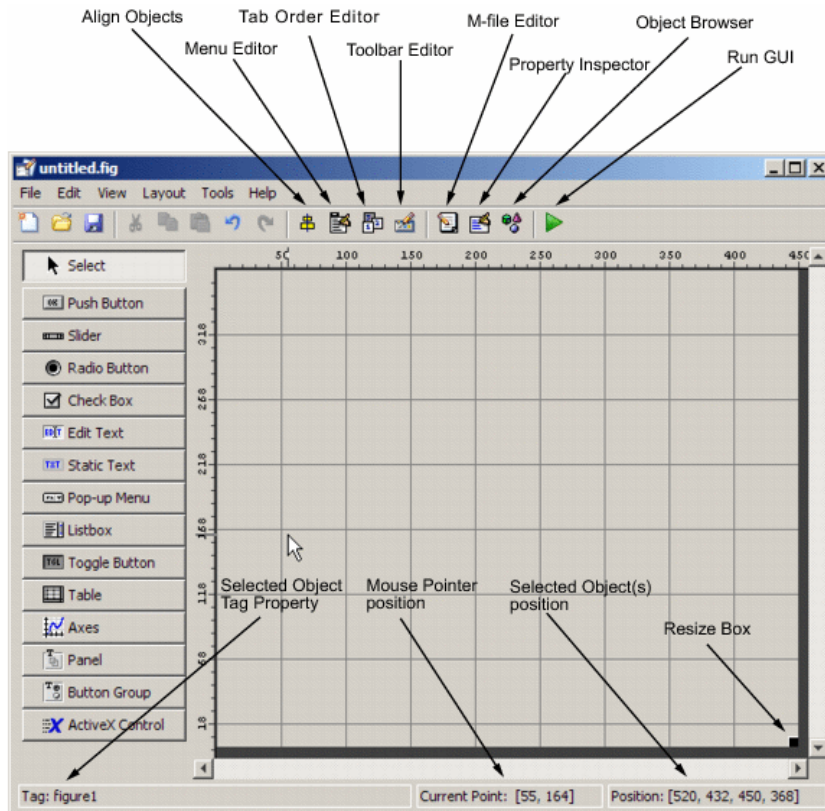


Figure 6 MATLAB GUIDE Platform (Mathworks, 2010)

```

70
71 % --- Executes on button press in tab1.
72 function tab1_Callback(hObject, eventdata, handles)
73     hObject    handle to tab2 (see GCBO)
74     % eventdata reserved - to be defined in a future version of MATLAB
75     % handles    structure with handles and user data (see GUIDATA)
76     set(handles.tab1, 'Visible', 'on');
77     set(handles.tab2, 'Visible', 'off');
78     guidata(hObject, handles);
79
80
81
82 % --- Executes on button press in tab2.
83 function tab2_Callback(hObject, eventdata, handles)
84     % hObject    handle to tab2 (see GCBO)
85     % eventdata reserved - to be defined in a future version of MATLAB
86     % handles    structure with handles and user data (see GUIDATA)
87     set(handles.tab1, 'Visible', 'off');
88     set(handles.tab2, 'Visible', 'on');
89     guidata(hObject, handles);

```

Figure 7 MATLAB Editor Code: Callback Functions (Mathworks, 2010)

Depending on the type of object, a command can be carried out when the user interacts with it in the GUI. These objects have callback functions for which the appointed task can be

programmatically dictated through the code. For example, when a user clicks a button in the GUI, a task is performed. However, this would not be the case for a static text object. Below is a table of the various objects that were used in the design of our program, a brief description, and whether callback functions were available for them.

Table 3 MATLAB GUIDE Objects used in Program

Objects	Description	Callback Function (Yes or No)
Static Text	Creates a text box to display instructions to the user	No
Button	Performs task when the user clicks on object	Yes
Edit Text	An editable text box that records user input	Yes
Check Box	Allows the user to choose multiple predefined options by clicking	Yes
Axes	Allows for graph creation within GUI inside specified bounds	Yes
Dropdown Menu	User chooses one of multiple predefined options	Yes

Values directly inputted by the user, as well as choices made by the user through predefined objects such as check boxes and dropdown menus, are able to be stored as variables. Variables can have the exact value entered or be assigned something entirely different according to the purpose of the program. For example, text options within drop down menus can be assigned numerical values for computation purposes.

Outputs can be programmed into the GUI in several different ways, through the use of various objects. Each object has its own object handles, which allow the coder to control its properties within the code. Handles can be used to manipulate objects to display a specified output.

PROGRAM OUTLINE

The program is effectively two-tiered: It first involves a characterization of risk to humans, computed in accordance to user input parameters and intrinsic data from scientific literature. Once the risk has been characterized, it may become necessary to reduce exposure levels. This involves exploring options for reducing exposure and subsequently recalculating risks to ascertain whether they are within acceptable range. The model thus subsequently compares mitigation strategies to promote the most efficacious regime for the farm specific parameters inputted.

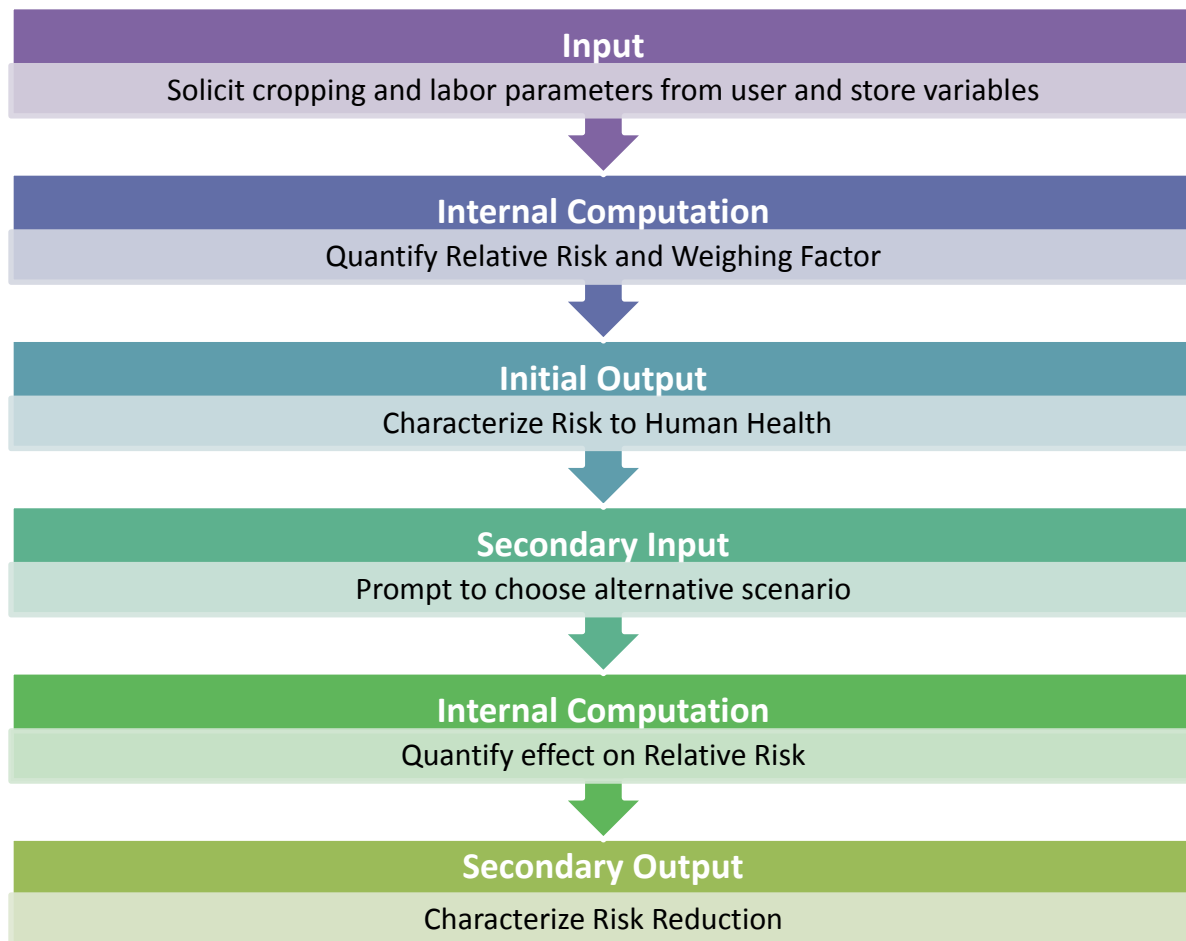


Figure 8 Summary of Program Structure

TARGET USER

The target user dictates how the system should be developed. While ultimately, it is preferred to develop a system that can be utilized directly by farmers to empower and provide educational assistance, in many rural regions of India farmers or farming organizations may not speak English, be literate, or may be unfamiliar with or lack access to the technology. This poses a great restriction to the usability of our program within the region specified. Certain issues can be resolved to a point, then, by considering the use of NGO's and government agencies as intermediaries through which farmers could have access to the benefits of the program without having to directly use the software. In this way, policy could be directly targeted.

In addition, the program is also targeted towards larger farm owners, who may be in a different income bracket than the small farmers and could have access to better resources, including technology and education. Although large farms make up a small percentage of farmers, the percentage of overall agricultural area operated through them is substantial.

INTERFACE DESIGN

Certain parameters had to be considered when creating the actual interface in order to optimize the usability of the program. Namely, the program had to be easily understood by the user without assistance. Aspects such as ease of navigation and a professional look were heavily considered.

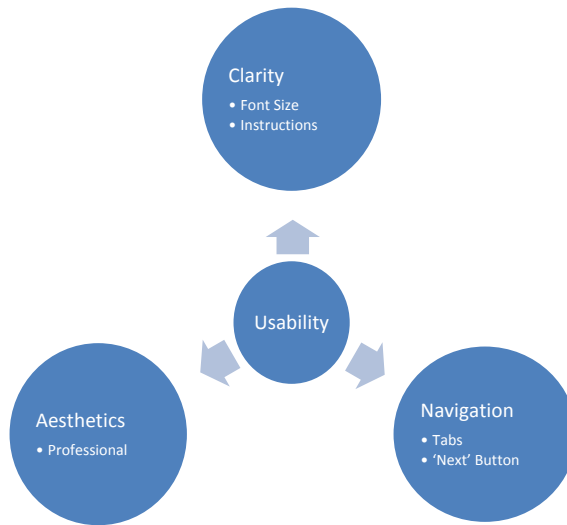


Figure 9 User Interface Parameters

DATA COLLECTION

The program was designed to solicit farm-specific cropping parameters from the user. (See Figure 10 below) These parameters are necessary to the health risk computation and entered through the use of several avenues available in the MATLAB GUIDE platform, each listed in Table 4 below.

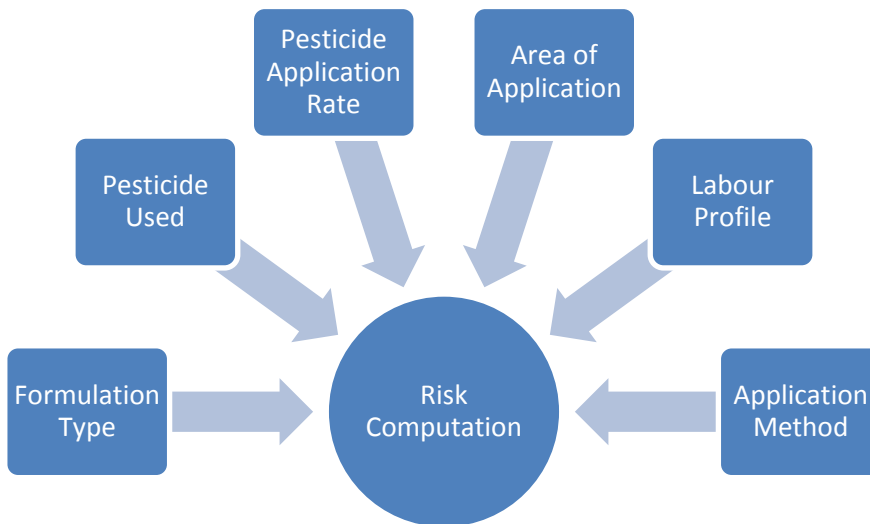


Figure 10 User Input Parameters for Risk Computation

Table 4, Summary of Relevant Parameters

Parameter	Value	Input Method
Pesticide Utilized	Pre-calculated Weighted Value	Dropdown Menu
Application Equipment	Pre-calculated Weighted Value	Dropdown Menu
Application Rate	g or mL per hectare	User Entered Text
Formulation of Pesticide	Pre-calculated Weighted Value	Dropdown Menu
Treatment Area	Expressed in hectares	User Entered Text
Use of Personal Protective Equipment (PPE)	Pre-calculated Weighted Value	Check boxes with Graphics
Number of Pesticide Operators	Number of People	User Entered Text

ASSESSING HUMAN HEALTH RISK

The methodology for the computation of human health risk is inspired by indices reported in the literature (QPRI, 2008) (Garreyn, 2003) (NAIS, 2003) (POEM, 2003). The potential of the pesticides to exert negative influences upon health can be defined as ‘risk’. The risk incurred by spray operators during the application of a pesticide is characterized both by the intrinsic risk potential of the chemical agent to induce adverse effects, and the magnitude of exposure opportunities. It can be mathematically described as:

Equation 1, Risk Described

$$\text{Total Risk} = (\text{Intrinsic Risk}) * (\text{Magnitude of Exposure})$$

The potential for the development of adverse health effects consequential to the occupational exposure to pesticide, otherwise defined as 'risk', depends on several factors, but largely is dictated by the: (a) types of pesticides handled, (b) frequency and duration of application and (c) intensity of application (Fenske, 2003). The intrinsic risk is therefore defined according to the inherent toxicology of the pesticide handled and the magnitude of exposure- thus described according to the frequency, duration and intensity of exposure. Expressed therefore relevant to the context of occupational pesticide exposure, risk is therefore characterized as:

Equation 2, Human Health Risk

$$\text{Health Risk} = \frac{(\text{Toxicological Risk}) * (\text{Exposure Risk})}{(\text{Scaling Factor})}$$

Whereby:

(Toxicological Risk) = The intrinsic toxicity of the pesticide

(Exposure Risk) = f (WApplicationType, WApplication Rate, WMitigation Coefficient)

- (WApplicationType) = Weighing factor to consider the application method
- (WApplicationRate) = Weighing factor to consider the rate of application
- WMitigation Coefficient = Weighing factor to consider use of mitigation strategies, for the initial risk computation it is assigned a value of 1.

(Scaling Factor) = Factor to reduce the risk index to a value relatable to the user

INTRINSIC TOXICITY

The intrinsic toxicity of the pesticide is defined according to a toxicological risk index (TRI). Various toxicological risk indicators have been developed and are described in the literature- most relevantly to the application herein described is: The Globally Harmonized System of Classification

and Labeling of Chemicals (GHS, 2005), United States Environmental Protection Agency (EPA, 2005)

The estimate of an intrinsic toxicity factor is a function of three component indices: acute risk, chronic risk and persistence potential. The TRI is achieved by summing scores assigned to different criteria characterizing for the acute and chronic toxicity- coupled by a factor describing the persistence and bioaccumulation potential of the compound. The relationship is summarized as:

Equation 3, Intrinsic Toxicity (QPRI, 2008)

$$\text{Intrinsic Toxicity} = \left[\sum \text{acute risks} + \left(\sum \text{chronic risks} \times \text{Persistence Factor} \right) \right]^2$$

The appropriation of relative severity scores for this index is described in Appendix A. The acute toxicity index quantifies risk from immediate, high concentration exposure opportunities. It is calibrated according to the severity of toxicological measures of dosage such as LD₅₀s (lethal dosage at which 50% of test animals are killed). Similarly, the chronic toxicity index quantifies risks from longer-term, lower-dosage exposure. It encompasses the capacity of an active ingredient to cause adverse health impacts such as cancer or impaired immune system function (Benbrook et al, 2008).

Both the acute and chronic risks are a function of their weighted relative contribution to toxicity and are defined according to the severity ranking system established by the Quebec Pesticide Risk Index Report (QPRI, 2008) summarized in Appendix A. For instance, the acute toxicity index can be obtained by summing values like the ones described in the table below:

Table 5, Acute Toxicity Determination- Adapted from QPRI (2008)

Acute Toxicity	Severity of Effects and Associated Weighing Points			
	8	4	2	1
LD ₅₀ Oral	≤ 50	> 50 - 300	> 300 - 2000	> 2000
LD ₅₀ Dermal	≤ 200	> 200- 1000	> 1000- 2000	> 2000

The toxicological characteristic of the pesticide are thus required to compute risk.

MAGNITUDE OF EXPOSURE

Intrinsic toxicity factors alone do not accurately describe risk, for risk is equally influenced by the magnitude of exposure opportunities. The magnitude of exposure is characterized according to frequency, intensity and duration of exposure. Consequentially, the nature of the occupational activity in which an individual engages, dictates the risk he/she is subject to. The frequency and duration of the application activity are dictated according to factors such as the size of land treated, the number of workers involved, and the method of application. Similarly, the intensity of exposure opportunities depends on factors such as the concentration and application rate (Garcia & Almeida, 1991). Amongst the factors described, the method of application is the most significantly representative of risk and accordingly, a weighing factor must be assigned for inclusion of this mechanism within the risk computation framework.

Weighing factors for technique of application are summarized below:

Table 6, Weighing Factor for Application Technique (QPRI, 2008)

Weighing Factor According to Technique and/or Place of Application		
1	1.5	2
<ul style="list-style-type: none"> • Use of pretreated seed • Incorporation 	<ul style="list-style-type: none"> • Horizontal boom spray unit • Air blast sprayer with ground directed spray • Sprayer with anti-drift system 	<ul style="list-style-type: none"> • Air blast sprayer with high position directed spray • Treatment of seed in closed area • Treatment in closed area

INTERPRETING RISK INDICES OUTPUT

The output values for the Health Risk Index can range anywhere from 1.25 and 23, 0404, though in the Quebec it namely ranges from 1.25 and 1560. From these ranges, a classification system for the risk index was created based on the assumption that the index rises proportionately.

Table 7, Risk Output Classification

Classification	Health Risk Value
Slight Risk	≤ 100

Moderate Risk	≥ 101 and ≤ 500
Strong Risk	≥ 501 and ≤ 1000
Severe Risk	≥ 1001

ASSESSING EFFICACY OF MITIGATION STRATEGIES

In brief, safety measures should act either to control toxicity or reduce opportunities for exposure. Strategies employed to mitigate occupational exposure are often expressed as a hierarchy, emphasizing the pivotal significance of engineering and administrative controls, and as a last resort, the use of personal protective equipment (Franklin & Worgan, 2005). The matter of administrative controls exceeds the scope of the development of the expert-system and accordingly is addressed exclusively in the proceeding discussion of implementation potential. The efficacy of engineering controls is determined by their potential to reduce interactions between workers and pesticides. For instance, mild reconfiguring of the design of a conventional pesticide sprayer can significantly redefine the risk scenario. The simple switching of the spraying unit from the front, to the back of the worker, coupled by replacing the traditional lance by a longer one reduced the potential dermal exposure (PDE) of workers by 93.3% (Tunstall et al, 1961).

As no health risk indices were identified in the review of the literature that considered the efficiency of mitigation strategies, it became necessary to develop a means to integrate these factors within the aforescribed computation of risk. The following section describes the methodology employed for integrating an adjustment factor to account for the efficacy of mitigation strategies to reduce risk. Refinement in this respect includes introducing models of occupational exposure and results from engineering control field trials into the computation of risk. The efficiency of a given risk reduction strategy is defined as follows:

Equation 4, Efficiency of Mitigation Strategy

$$\text{Efficiency of Mitigation Strategy} = \left(\frac{HR_0 - HR_m}{HR_0} \right) * 100$$

Whereby

HR_0 = Health Risk for current field practices without mitigation strategies

HR_m = Health Risk considering application of mitigation strategy

A modified risk index HR_m must therefore be developed. The methodology for achieving the index is similar to the one described above.

Equation 5, Modified Health Risk

$$\text{Health Risk} = \frac{(\text{Toxicological Risk}) * (\text{Modified Exposure Risk})}{(\text{Scaling Factor})}$$

Whereby the parameters are the same as those described above with exception to:

(Modified Exposure Risk)= Factor considering exposure including mitigation strategies

The exposure during specific handling events can be modified by several important factors, described as follows: (Fenske et al., 2003)

- Type of equipment used
- Formulation and packaging
- Environmental conditions
- Personal protective equipment
- Hygienic behavior
- Duration of activity

Amongst the factors identified, the type of equipment used and the duration of the activity are managed by engineering controls. No influence can be exerted upon environmental factors, as such they are not considered further. Formulation and packaging, as well as hygienic behavior can be modified by the implementation of legislation and education and accordingly exceeds the scope of expert-system development.

Mitigating the extent of occupational exposure (i.e. reducing the amount of chemicals entering the body) depends largely upon:

- Reducing the amount of product or dilutes spray entering the breathing zone

- Reducing the amount of product or dilute spray contaminating the external surface of the worker.

In the former, the amount of pesticide (concentrate or dilute spray) inspired into the lungs is a function of the particle size, amount entering the breathing zone, and amount inhaled:

Equation 6, Inhalation Exposure

$$\text{Inhalation Exposure} = f(\text{Amount Entering Breathing Zone, Amount Inhaled, Droplet Size})$$

While not all the pesticide entering the breathing zone will be inhaled and furthermore, only a fraction of the inhaled portion will be respired into the lungs (POEM, 2003), quantifying inhalation exposure depends on the droplet size entering the breathing zone. As these parameters have not yet been characterized, it must therefore be assumed that all of the chemical entering the breathing zone will be relevantly absorbed into the blood stream. In this respect, the inhalation exposure is defined very similarly to that of dermal exposure. Given the gaps in the literature, appropriating mitigation strategies for the reduction of inhalation exposure will be estimated as being equivalent to that for mitigating the amount of dermal absorption. These exposures are therefore reduced either by implementing personal protective equipment or engineering controls. A summary of relevant efficacy studies is provided in the table below and the methodology for incorporating these means into the health risk index is described in the proceeding sections.

Table 8, Summary of Representative Literature on Efficacy of Various Controls

Summary of Literature on Efficacy of Engineering Controls		
Mitigation Strategy	Conclusions& Comments	Author/ Year
<ul style="list-style-type: none"> • Modification to sprayer: V-Shaped Boom design which offers protection by distance 	<ul style="list-style-type: none"> • Dermal exposure: 1864.7 → 166.8 mL/hr • Controlled effects of wind • Mean efficiency: 91.0% in the control of worker drenching • Work more comfortable, lighter and rapid 	Neto et al. 1992
<ul style="list-style-type: none"> • Knapsack sprayer from front to back of body 	<ul style="list-style-type: none"> • Dermal exposure reduced by 95% 	Tunstall & Matthews, 1965
<ul style="list-style-type: none"> • Lengthening the spraying lance • Switching nozzle position to back of sprayer's body 	<ul style="list-style-type: none"> • Potential dermal exposure: reduced by 35% • Attaching the lance to back of tank reduced it by 98% 	Neto et al.,1998
<ul style="list-style-type: none"> • Compare traditional handheld spray equipment to novel spray application 	<ul style="list-style-type: none"> • Dermal exposure reduced by 20, 60 and 8 times with novel spray techniques relative standard spray gun. 	Nuyttens et al. 2008

techniques		
<ul style="list-style-type: none"> Field study to evaluate the ability of protective garments to reduce worker exposure using fluorescent tracers and imaging 	<ul style="list-style-type: none"> Cotton coveralls= 72.7% exposure reduction Coveralls + gloves= 93.5% exposure reduction Coveralls + gloves+ face shield= 94.9% reduction 	Fenske et al. 1993
<ul style="list-style-type: none"> Exposure study involving boom- hydraulic nozzle with cab 	<ul style="list-style-type: none"> Inhalation exposure= 0-0.2 ml/hour Dermal exposure=0-50 ml/hour 	POEM, 1992
<ul style="list-style-type: none"> Exposure study involving rotary disk atomizer with cab 	<ul style="list-style-type: none"> Inhalation exposure=0-0.1 ml/hour Dermal exposure=0-10 ml/hour 	POEM, 1992
<ul style="list-style-type: none"> Exposure study involving handheld hydraulic nozzles 	<ul style="list-style-type: none"> Inhalation exposure= 0-0.2 ml/hour Dermal exposure=1-200 ml/hour 	POEM, 1992
<ul style="list-style-type: none"> Exposure study involving handheld disk atomizers 	<ul style="list-style-type: none"> Inhalation exposure=0-0.2 ml/hour Dermal exposure high=0-200 ml/hour Dermal exposure low=1-100 ml/hour 	POEM, 1992

PERSONAL PROTECTIVE EQUIPMENT

It has been well documented that the most important route of occupational exposure involves dermal absorption (Antle & Pingali, 2004). The rate of absorption depends on the concentration interacting with the dermal surface, the area of the body that is contaminated, the integrity of the skin surface and prevailing climatic conditions. Clothing presents an effective barrier to penetration by dilute spray. The extent to which aqueous pesticide sprays will penetrate clothing is dependent upon both the material of which the clothing is made and the design of the particular garment being worn (Matthews, 1979). The mitigation potential of personal protective equipment can be integrated into risk analysis according to the following relationship, which describes the risk of the total occupational workforce as the risk allocated to those wearing personal protective equipment plus the risk allocated to those without:

Equation 7, Occupational Risk Index Considering PPE

$$RI_{Consider\ PPE} = (RI_{ppe}) * (\%PPE) + (RI_{noPPE}) * (1 - \%PPE)$$

$RI_{APPLICATOR}$ = Applicator risk index with consideration of personal protective equipment

(RI_{ppe}) = Risk index coefficient for a specified personal protective equipment

$(\%PPE_k)$ = Percentage of labor group wearing personal protective equipment

(RI_{noPPE}) = Risk index coefficient describing absence of personal protective equipment

$(\%PPE)$ = Percentage of labor group not wearing personal protective equipment

The availability of compliance data is typically scarce and when available, may often not be meaningfully interpreted for the application herein described. The risk index is thus computed upon the assumption that personal protective equipment is worn universally by all workers. The equation is thus refined to:

$$RI_{Operator} = (RI_{ppe}) * (\%100 PPE)$$

Consequential to the above described assumption, the risk derived by this method will overestimate the mitigation potential and therefore represents the maximum mitigation efficacy. We propose employing the following relationship inspired by the equations described by

Equation 8, Operator Exposure

$$\text{Risk Operator} = (\text{Rmixload} + \text{Rapplication}) * \frac{\text{AR}}{\text{BW}} * \text{Areatreated}$$

$$\text{Rmixload} = [(PPE_i * A_{bi}) + (PPE_{hand} * A_{bd})]$$

$$\text{Rapplication} = [(PPE_i * A_{bi}) + (PPE_{hand} * A_{bde}) + (PPE_{body} * A_{bdermal})]$$

Whereby

- A_i, A_d, A_b are coefficients defining the differential in absorption between the skin and the protective equipment
- $PPE_i, PPE_{hand}, PPE_{body}$ are values defining whether or not personal protective equipment was worn. Wearing was assigned a value=1, Not wearing was assigned a value=2

The **Rmixload** & **Rapplication** differ only the values of absorption given that mixing and loading applications typically involve concentrates whereas application involves dilute sprays. Representative values of reduction coefficients for personal protective equipment during mixing/loading and application phases.

Table 9, Reduction Coefficients for PPE (POEM, 2003)

Default Values of Personal Protective Equipment Reduction Coefficients			
Phase	Inhalation (mask)	Hands (glove)	Body (overall)
Mixing/Loading	0.1	0.1	-
Application	0.1	0.1	0.2

Analysis of the sensitivity of these parameters revealed that they do not differ significantly and accordingly for simplicity of the model, they are integrated into a single parameter defined as **Roperator**. The equation is thus refined to

Equation 9, Modified Operator Risk

$$\text{Risk Operator} = (\text{Roperator}) * \frac{\text{AR}}{\text{BW}} * \text{Areatreated}$$

- **Roperator** = [(PPEi * Abi) + (PPEhand * Abde) + (PPEbody * Abdermal)]
- **AR** = Application Rate
- **BW** = Body Weight → Surrogate value of 80kg used
- **Areatreated** = Hectares/day

AGRICULTURAL EQUIPMENT AND MECHANIZATION

As described in the preceding section in which the occupational activities were contextualized, the method of pesticide application is most frequently performed with operator-carried or vehicle mounted spray equipment, each of which possessing an intrinsic exposure potential to the pesticide operator. The summary of literature revealed that operator-carried application techniques posed significantly less risk than their vehicle mounted counterparts for dermal exposure, although inhalation exposure did not differ significantly. Furthermore, the literature on the matter revealed that modifications to the design of the operator-carried equipment, such as lengthening spray lance and more efficient nozzle delivery systems, introduced significant opportunity to reduce risk. Given that no models or equations describing these relationships do not exist, a methodology for incorporating these values into the risk assessment computation was developed. Effectively the (**Modified Exposure Risk**) parameter of Equation 5 was defined as follows.

Equation 10, Mitigation of Engineering Controls

$$(\text{Mitigation K}) = (\% \text{Mitigation Potential}) * (\% \text{ of Total Time})$$

Whereby

(%Mitigation Potential)

= The percent reduction in operator exposure due to control, results derived from

(% of Total Time)= The parentage of the total occupational time/day the activity for which control was introduced occupies

In this case, the (**Modified Exposure Risk**) parameter of Equation 5 is therefore defined as follows.

$$(\text{Modified Exposure Risk}) = (\text{TRo}) * (1 - \text{Mitigation K})$$

Whereby

(TRo)= Risk without consideration of mitigation strategies

For instance, a closed-cab mitigation strategy that reduces operator exposure by 95%, in which the time occupied performing the activity for which the mitigation strategy was employed is 30% of the total work day, yield a Mitigation K coefficient = (95%)*(30)= 28.5%. implying therefore that the strategy reduced exposure by 28.5%. Integrating this value into the risk reduction computation implies that 71.5% of the initial exposure remains.

FINAL DESIGN

The end product incorporates the design criteria into one program able to calculate a relative health risk as well as provide mitigation strategies for users. The final design incorporates the use of tabs through which users can navigate four different sections shown in the figures below. The first two panels solicit information from the user, the third presents the calculated risk outcome, and the fourth allows for the exploration of mitigation strategies.

Figure 10, Health Risk Calculator: Field Profile

Field Profile	Labour Profile	Risk Outcome	Alternative Senarios
Instructions for Using Health Risk Calculator Complete each section by filling in the answer boxes, starting with 'Field Profile.' Click the 'Next' button to continue to the next section or click on the tabs above to move between them. In this section, you make a profile of the field that is being treated with the pesticide. 'Field name', 'Year', 'Season', 'Crop Grown' and 'Targeted Pest' are used purely for personal records and do not effect the risk calculation. * Indicates a required box.			
Field Name <input type="text"/> Year <input type="text"/> Season <input type="text"/> Crop Grown <input type="text"/> Targeted Pest <input type="text"/> Commercial Product Applied* <input type="text"/> Application Type* <input type="text"/> Amount Applied* <input type="text"/> g or mL Area of Field Treated* <input type="text"/> ha Formulation Type* <input type="text"/>			
			Next

Figure 11, Health Risk Calculator: Labour Profile




Field Profile	Labour Profile	Risk Outcome	Alternative Senarios
Instructions for Using Health Risk Calculator Complete each section by filling in the answer boxes. Click the 'Next' button to continue to the next section or click on the tabs above to move between them. In this section, you will enter a labour profile for the field being treated with the pesticide. * Indicates a required box.			
Number of People Applying Pesticide* <input type="text"/> Personal Protective Equipment Used by Pesticide Handlers* (Check all that apply or choose 'None')			
<div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;">  <input type="checkbox"/> Gloves </div> <div style="text-align: center;">  <input type="checkbox"/> Protective Clothing </div> <div style="text-align: center;"> <input type="checkbox"/> None </div> </div> <div style="display: flex; justify-content: space-between; margin-top: 20px;"> <div style="text-align: center;">  <input type="checkbox"/> Mask </div> <div style="text-align: right;">Next</div> </div>			

Figure 12, Health Risk Calculator: Risk Outcome

Field Profile	Labour Profile	Risk Outcome	Alternative Senarios
<p>Instructions for Using Health Risk Calculator</p> <p>This section calculates the overall Health Risk associated with treatment for the information entered in the previous sections. Press 'Calculate' to compute the Health Risk Indicator (HRI). Click the 'Next' button to continue on to the next section and explore mitigation options.</p>			
<p>Field Name: Year: Season: Crop Grown: Targeted Pest:</p>		<p>Strong Risk for Adverse Health Effects The Health Risk Index (HRI) is calculated by multiplying the intrinsic risk of the pesticide with the level of exposure a worker experiences. The Health Risk Index is on a per hectare basis. The level of risk for the entire field is 3750. It is recommended that mitigation strategies be explored in order to lower this level of risk. The next tab should be consulted for further exploration.</p>	
<p>Calculate</p>		<p>HRI: 750 Per Hectare</p>	

Figure 13, Health Risk Calculator: Alternative Scenarios

Field Profile	Labour Profile	Risk Outcome	Alternative Senarios
<div> <div> <p>1 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0</p> <p>0 0.2 0.4 0.6 0.8 1</p> </div> <div> <p>Alternatives</p> <p>Calculate</p> </div> </div>			

IMPLEMENTATION

Real world implementation of this project requires further work be done in order to perfect the end product and make it a viable method for risk assessment by farmers in the Indian state of Punjab. Firstly the program would have to be compiled into an independent program which did not rely on the MATLAB software to run. This is possible through the use of MATLAB programming toolboxes through which creation an .exe program is feasible. Once independent of MATLAB, the possibility for distribution of this program would greatly increase. In addition, usage would not be hindered by the requirement of already having MATLAB installed, which is not viable considering its limited use and expense.

A user manual is also necessary that would further explore risk assessment including topics such as more detailed instructions to the use of the software, background on how calculations are made, financial advantages of health risk reduction, and educational tools as to the severity of exposure to pesticides on human health.

The next step would be to translate the program into a more suitable language, such as Punjabi or Hindi. Further considerations of socio-economic dilemmas may see changes made to the interface as well to better benefit the target audiences. This could potentially be accomplished with the help of the Punjab Agricultural University, a world renowned university in its field through collaborative efforts. The location and expertise of this university would greatly aid in the objective of this program as a viable tool for mitigation of pesticide exposure.

With these things accomplished, distribution of the program could take place on a wider scale. NGO's could play a role in making the program available to marginal farmers who may have less access to technology. By involving those involved in policy making, the larger goal of promoting best management practices could be more attainable.

The cost of implementation would be minimal as once the program is independently executable, it could be made available online for free as open source software. In this manner, improvements could be made by a larger international community, as well as be redefined for use elsewhere.

LIMITATIONS OF THE MODEL

NO CONSIDERATION OF FINANCIAL AND ENVIRONMENTAL PARAMETERS

Although environmental consequences do not constitute the parameter of emphasis for optimization in the proposed software, consideration of environmental risk factors constitutes an important realm when developing a health risk mitigation strategy. That is, an optimal pest management strategy is one that mitigates occupational pesticide exposures while maintaining ecological integrity. Humans do not exist as a dichotomy with the environment but rather, exist as permeable members to it. Environmental contamination threatens the integrity of human health and accordingly, a strategy should not be adopted if it threatens to produce such results. This is true also of financial risk. The ideal system is one in which the financial, environmental, and financial risks are mutually optimized for mitigation. Indeed, various environmental and financial risk assessment models have been developed and the framework for their application within the expert system could be done in accordance to the methodology described for human health risk. Furthermore, the programming code necessary to achieve this adoption could readily be adapted within the existing software system.

LIMITATIONS IN ASSESSING TOXICOLOGY

Another issue of the system involves the fact that currently, no consensus exists in the literature on the most effective method to measure health impacts from agricultural chemical applications. While the literature recognizes the potential of these compounds to pose discernable impact to human health, no agreed upon methodology exists to measure this impact (Greitens & Day, 2007). Accordingly, the toxicological risk factors and the appropriation of severity scores may not accurately reflect the true risk. Furthermore, while traditionally pesticide risk assessment models have been developed on single products, it is increasingly recognized that interactions between multiple pesticides may pose synergistic consequences. Therefore, risk assessment of pesticides should more accurately be adapted to consider the toxicology potential of mixtures of chemical compounds. Furthermore, there is no factor attributed to consider the composition of the population. The risk for sensitive population groups contributes, as a default, for 5% to the total risk (Hemmen, 2006). There is no factor in the model to consider either pediatric or gender-relevant susceptibilities. By applying weighting coefficients to the actual/local parameters that may affect the likelihood of exposure of the sensitive/susceptible population of susceptible subjects

or subgroups will be taken into account. Finally, further in this respect involves the fact that the efficiency of risk mitigation strategies are based heavily on empirical evidence from field studies. When such studies are conducted in regions other than the one for which the results are immediately described, extending their conclusions to the context of Punjabi agriculture may not be necessarily relevant.

MITIGATING OF INTRINSIC TOXICITY NOT CONSIDERED

While the expert-system herein described principally involved mitigation strategies that sought to reduce risk by reducing the exposure of the operator to the pesticides, risk could also have been addressed by adoption of other mitigation strategies involving lesser intrinsic toxicity values—namely, these involve biological agricultural systems of which organic agriculture and integrated pest management (IPM) are the most important means. Unfortunately no studies exist in the literature that characterizes the potential of organic agricultural systems and IPM regimes to mitigate the intrinsic and exposure risks of pesticide usage. Accordingly, the potential of such strategies to reduce operator risk could not be evaluated within the scope of the project. However, very intuitively these systems bear a significantly lesser intrinsic risk and are worthwhile considering. The following offers a discussion on the matter.

Biological agriculture involves cultivation that is in abidance to production standards that prohibit the use of synthetic insecticides and herbicides, human waste, food additives, hormones, antibiotics and may sometimes exclude the cultivation of genetically modified crops. Amongst biological cropping systems, IPM systems are those favoring biological pest control techniques whose intrinsic toxicity is lesser than those of conventional synthetic means. IPM systems promote methods that disrupt pest cycles, including strategies such as insect predators, and biopesticides. The primary criticism, for which biological agricultural systems have been subject, involves their ability to adequately meet population food requirements. While concerns of compromised efficiency and yields are common criticisms of such systems, these claims may not necessarily be substantiated by results from field studies and scientific literature. Literature on the matter has produced mixed results. A comprehensive twenty-two year study conducted by the Rodale Institute compared soybean and corn yields between conventional and organic cropping systems. Results suggested that corn yields were similar between conventional and organic cropping systems (Pimentel et al, 2008). Despite the concern for reduced crop outputs, the farmer's financial integrity

need not necessarily be comprised by the adoption of organic cropping practices. Price ranges for organic produce are typically between 20% -140% higher than conventional produce, and fossil energy inputs are roughly thirty percent less, thus rendering the differential crop yields insignificant with respect to matters of finance (Badgley et al, 2007).

CONCLUSIONS

The development of the final product was achieved after an extensive design process. It takes into consideration the design criteria laid out in the initial stages of planning as well as alterations in later stages. The MATLAB program provided an efficient means through which a successful program with a working GUI and risk calculator was created.

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APPENDICES

APPENDIX A – RISK CHARACTERIZATION VALUES

The following tables summarize the appropriation of scores assigned to characterize the relative contribution of each effect for the computation of risk.

Table 14, Acute Toxicity Indices

Acute Toxicity	Severity of Effects and Associated Weighing Points (QPRI, 2008)			
	8	4	2	1
LD ₅₀ Oral	≤ 50	> 50 - 300	> 300 - 2000	> 2000
LD ₅₀ Dermal	≤ 200	> 200- 1000	> 1000- 2000	> 2000
LD ₅₀ Inhalation	≤ 0.5	> 0.5 - 1	> 1-5	> 5
Dermal Irritation	Severe - extreme irritant	Moderate Irritant	Slight Irritant	Little - no irritant

Ocular Irritation	Severe - extreme irritant	Moderate Irritant	Slight Irritant	Little- no irritant
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Table 15, Chronic Toxicity Indices

Chronic Toxicity	Severity of Effects and Weighing Points (QPRI, 2008)				
	16	8	4	2	1
Carcinogenicity	Human Carcinogen	Probable Human Carcinogen	Possible Human Carcinogen	Cannot assess risk of human carcinogenicity	Inadequate Data
Genotoxicity	-	Genotoxicity for humans	Potential Genotoxicity for Humans	-	Inadequate Data
Endocrine Disruption	-	Evidence of Endocrine Disruption	Potential Endocrine Disruption	-	Inadequate Data
Reproductive Effects	Confirmed Human Effects	Suspected Human Effects	Confirmed Animal Effects	Suspected Animal Effects	Inadequate Data
Development	Confirmed Human Effects	Suspected Human Effects	Confirmed Animal Effects	Suspected Animal Effects	Inadequate Data

Table 16, Environmental Persistence and Bioaccumulation Indices

Classification of persistence and bioaccumulation potential (QPRI, 2008)	FPer
Soil half-life \geq 60 days	3.0
Soil half-life \geq 30-60 days	2.5
Soil half-life \geq 15-30 days	2.0
No data available	1.5
Soil half life < 15 days	1.0

Table 17, Weighing Factor for Application Technique

Weighing Factor According to Technique and/or Place of Application (QPRI, 2008)		
1	1.5	2

- | | | |
|---|--|--|
| <ul style="list-style-type: none"> • Use of pretreated seed | <ul style="list-style-type: none"> • Horizontal boom spray unit | <ul style="list-style-type: none"> • Air blast sprayer with high position directed spray |
| <ul style="list-style-type: none"> • Incorporation | <ul style="list-style-type: none"> • Air blast sprayer with ground directed spray • Sprayer with anti-drift system | <ul style="list-style-type: none"> • Treatment of seed in closed area • Treatment in closed area |