THE ECONOMIC EFFICIENCY OF CHEMICAL DETECTION: HOW DO WE EVALUATE COST-EFFECTIVENESS OF CHEMICAL DETECTION?

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INTRODUCTION

Sensors for detection, identification, and analysis of chemical threats are an important part of civil emergency response and military force protection. Large amounts of money are spent every year on the development, production, and procurement of sensors. Detection, however, is rarely an end unto itself. Sensors are used for intelligence, warning, incident response, surveys, health and safety monitoring, and myriad other uses. Sensors are rarely cheap; many are quite expensive. In comparison to training, protection, decontamination, and other possible expenditures, the author knows from direct experience that sensors can consume a rather large proportion of an agency's CBRN budget. In the author's opinion, there is a distinct lack of understanding of the economic practicalities of CBRN sensors. There is a lack of effective tools to evaluate the cost-effectiveness of CBRN sensors. Simply stated, does a 100,000 Euro chemical detector perform ten times as much work or provide ten times as much value as a 10,000 Euro detector? The answer is that nobody knows. The response community does not yet have the tools in its toolbox to accurately answer the question. How can officials and leaders make useful comparisons between different courses of action in chemical detection development, acquisition, and procurement without the necessary objective tools to perform a sound comparison?

SENSORS AS INFORMATION TOOLS

In professional response circles, the actual nature of sensors is often lost in the noise. Manufacturers and responders alike often speak of detection, identification, and monitoring as ends unto themselves. In reality, however, chemical sensors are only information tools. A sensor translates physical phenomena into information. This information can be used to make decisions and take actions. However, long before the advent of sensors, people have been making decisions and taking actions. So, clearly, it is possible to take actions without a detector.

There is no clearly defined index or scheme of measurement that can be used to make fair comparisons between different types of detectors. Information provided by detectors could be measured both quantitatively and qualitatively. At the elemental level, information quantity can be measured directly as a flow of binary numbers. However, capturing and measuring the baud rate of data reported by a detector is, in itself, a useless task as such a measurement scheme does not provide for any measurement of what quality the information might have. Information can have negative quality. Bad information can lead to bad decisions and actions, and so bad information is of negative value. In order to develop a useful way to make useful comparisons between different detectors, we must find a way to use both quantity and quality as measures. A large amount of information of bad quality is of far less value than a small amount of information of good quality. There is no objective measurement scheme at present that accomplishes this task. Development of such a scheme would be of immense value and may be an excellent line of inquiry in future symposia.

ECONOMICS OF DETECTORS

When a person invests money in a financial instrument, one can calculation the accrued benefits as a "return on investment." With automobiles, it is commonplace to use a miles-per-gallon or liters per kilometer approach to measure the vehicle's efficiency. Chemical detection provides no such easy measurement. It is only possible to make direct comparisons within a very narrowly defined subset of detection equipment. For example, handheld chemical warfare agent detectors can be directly compared to each other. It is also important to calculate indirect costs, as well as the direct expense of a detector. For example, some detectors might require an hour of training and few consumables or maintenance, but a more complicated detector might require a week or more of specialized training, expensive consumables, and/or significant maintenance over the course of its service lifetime.

In the absence of a useful way of measuring both quantity and quality of detection information, the practical approach to use in this line of inquiry is to assess the concept of valued added by detection. In its most basic form, we can define and assess the "value added" by the use of chemical detectors. In situations involving chemical warfare, incidents, or accidents, the decisions made by people (leaders, commanders, responders) are made by human intellect based on inputs. These inputs can be intellectual, sensory (what we see and hear), or technological (what machines tell us.) A detector is a technological input to this human decision-making. The "added value" (AV) of a detector can be derived by determining what difference the detector made to actual operations. In other words, did the detector cause a different decision or course of action to be made? In a military context, added value can be measured in terms of operational impact:

Broadly speaking, the value added provided by a detector can provide four categories.

1. Negative AV: The detector provides bad information that causes a situation worse than if the detector was not used. Example: Fatalities or injuries occurring due to excess traffic and panic if an evacuation is announced based on a faulty detection event.
2. Zero AV: The operator or decision-maker makes the same decision that they would have without the detector. Example: A detector has instilled so little confidence in its users that the alarm is turned off or ignored.
3. Moderate AV: Minor changes are made to a course of action, differing from the courses of action that would have been made without the detector. Example: A detector is able to discriminate between a persistent and a non-persistent chemical agent, affecting tactical decision-making.
4. High AV: Use of the detector has provided information that has made a substantial operational impact. Example: A detector operates correctly, provides warning, and saves lives.

It is important to note that evaluation of detectors using this admittedly crude categorization depends not just on the actual nature of the detector but also on the tactics, techniques, and procedures used in their employment. We cannot evaluate the usefulness of a detector in the abstract based solely on its specifications. It should be evaluated based on the intended use. Improper use of detectors can render them useless. Likewise, there are some situations where a skilled user can obtain useful information from a poor detector.

SPECIFIC COMPARISONS

Using the basic categories listed above, it is now possible to make some basic comparisons between detectors. Detectors can be plotted on a chart, even if only crudely. Figure 1 shows a basic scheme for plotting cost versus added value. Within the scope of a brief paper, the only way to illustrate the situation is to pose several example cases. For purposes of simplicity, this comparison will restrict the scope to the detection and identification of chemical warfare agents. This paper uses four types of commonly used chemical detection equipment. This paper makes no specific reference to any particular detector or manufacturer; generic examples indicative of detector types generally available on the market are used. In these scenarios, we will assume that all four detectors are used by the same operator, with a fundamentally sound concept of employment. This is necessary for a fair comparison. For each of our four scenarios, the cost and added value will be assessed, albeit crudely.

SCENARIO 1

Detection Paper: Detection paper is a venerable low-technology product used to characterize or even identify chemical warfare agents in liquid form.

Cost: Detector paper tends to be extremely cheap and easy to use, often being issued to soldiers at the lowest level. Indirect costs are low, as training is simple and there is no lifecycle maintenance cost.

Added Value: Employed properly, the information provided by detector paper can provide moderate amounts of tactically useful information. For example, the ubiquitous NATO M8 paper allows for detection and classification of visible amounts of liquid chemical warfare agent. Also, used properly, such detector paper can rule out the presence of liquid H, G, and V series chemical warfare agents. In many tactical situations, ruling out the presence of a chemical warfare agent is just as valuable as detecting its presence.

Assessment: When plotted on our chart, this detector is low-cost but provides a low to moderate degree of information.

SCENARIO 2

Ionization-based Chemical point detector: The ion mobility spectrometry (IMS) or flame ionization-based chemical detector has been ubiquitous for over thirty years and is the most widespread automated means for detection of chemical warfare.

Cost: Cost is generally moderate for this category of equipment. While certainly not cheap, these devices are cheap enough to become widespread in modern militaries and are certainly cheaper than some other categories of instruments. Some, such as the US JCAD, are being procured in such large quantities (and at a low price) as to become ubiquitous in the US military. Large contracts have allowed this category of detector to become a true mass-production item, which has made for economies of scale, thus resulting in a cheaper product. When taking inflation into account, this category of detector has become much cheaper in absolute terms over the course of the last two decades. Indirect costs, such as training and consumables, are typically moderate for this category of equipment.

Added Value: This category of detection is able to provide relatively sensitive and selective detection as well as classification or identification of the full scope of chemical warfare agents. Many such instruments are also capable of determining concentration, even at quite low levels. Technology has evolved to a state where this category of detector can be operated unattended and can be utilized in conjunction with wireless communication and GPS, so that the user has detection, concentration, identification, location, and time information from a single instrument at a single location on the battlefield. When used properly, this category of detector has high added value.

Assessment: This type of sensor can be categorized as relatively low cost but providing a high degree of information.

SCENARIO 3

Gas chromatograph / Mass Spectrometer (GC/MS): The GC/MS is widely viewed as a "gold standard" tool for analysis of chemical vapors. The techniques of gas chromatography and mass spectrometry, when used together, can provide a highly accurate analysis of the composition of a vapor sample.

Cost: Both the direct and indirect expense of these devices is quite high. The direct cost of GC/MS can be an order of magnitude higher than IMS devices described in scenario 2. The mechanical and electronic components of such a device are larger, more complicated, and more expensive to produce than IMS or flame ionization detectors. Training is more complex, maintenance is more expensive, and the general cost of ownership over a product's life-cycle is high.

Added Value: In a military or emergency response setting, GC/MS this can provide extremely accurate information. The nature of the technology greatly reduces false alarms as interferents are accurately characterized. The information provided by such an instrument will have higher value. Similar to scenario 2, identification, concentration, time, and location will all be provided by good use of GC/MS. GC/MS provides slightly more added value than the scenario 2 detectors.

Assessment: GC/MS provides high added value at a high cost, placing it in the top right corner of the evaluation chart.

SCENARIO 4

Passive standoff detectors: Standoff detectors have been available for twenty years. They typically use Fourier Transform Infrared techniques and examine infrared light from ambient background. These instruments measure the absorption of infrared light as it passes through a vapor cloud. This means that chemical warfare agent vapors can be detection, in principle, a number of kilometers away from the sensor.

Cost: Direct and indirect costs are high for this category of equipment. Indeed, they are among the most expensive chemical detection instruments on the market. The cost of standoff detectors is in a similar order of magnitude as GC/MS sensors.

Added Value: The information provided by such instruments can be useful. However, the scope of decisions that can be made based on this information is not any greater than that of an IMS point detector, and the quality and accuracy is certainly lower than that of a GC/MS detector. This is because this category of detector, while able to detect at a standoff distance, cannot provide useful range or concentration information. A deep but diffuse cloud appears the same as shallow and dense cloud. While range data might be conceivably possible using two or more detectors, this assumes favorable geometry and multiplies the cost.

Assessment: Standoff detectors provide moderate value added, but at a very high cost.

Figure two shows the four scenarios plotted on our chart.

OPPORTUNITY COST

It is important to note the concept of "opportunity cost." Financial resources are limited. No entity has unlimited resources for procurement of chemical detectors. Funds expended on one category of equipment means that fewer funds are available for other categories of equipment. A military that spends resources on a handful of very expensive high-end reconnaissance vehicles, with GC/MS and standoff detectors might do so to the detriment of point detectors proliferated among infantry companies and platoons.

CONCLUSION / HYPOTHESIS FOR FUTURE RESEARCH

The scenarios described above are relatively primitive abstract comparisons. We cannot yet answer the question "does a 100,000 Euro chemical detector perform ten times as much work or provide ten times as much value as a 10,000 Euro detector?" However, it is possible to estimate that the answer is probably a firm "No". The author believes that this general concept is a useful starting point of a more realistic approach to sensor procurement. An intelligent decision-maker will want to get the most possible added value for a given amount of budget. While sophisticated sensors gather much useful information, their direct and indirect costs conspire to ensure that they will always be scarce on the modern battlefield. Furthermore, money spent on scarce expensive sensors is not available for cheap and plentiful sensors. The author proposes the following hypothesis for future research: "Proliferation of cheap sensors around the battlefield is a superior policy than having a smaller quantity of more expensive and sophisticated sensors."