Setting the Specification Framework of an Early Warning System Using IDEF0 and Information Modeling

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ABSTRACT

Our goal is to develop an Early Warning System for an engineering system with a special interest in applying this to a material recovery facility. This on-going research points out that there is no clear definition of what Early Warning Systems are. A literature search for Early Warning Systems identifies hundred of thousands hits (Buchanan-Smith, 1999; Davies, Buchanan-Smith, Lambert, 1991). Almost all of the references had to do with financial systems for third world countries, tracking the destructive nature of violent conflicts that led to human suffering, or systems for syndromic surveillance. The goal of our research, and of this paper, is to define a framework for creating a specification that can be considered as the basis for the development of any Early Warning System – specifically for engineering systems. Therefore, we will describe Early Warning Systems and its requirements and specifications. Based on specification patterns, we have developed an abstract model of an Early Warning System; and developed an IDEF0 model of a material recovery facility that provides the framework for specifying an Early Warning System. The Early Warning System is then specified using information modeling.

Keywords

IDEF0 modeling, early warning system, requirements, specifications, analysis, disaster, SADT, sensors, data collection, EXPRESS, information modeling, material recovery facility.

INTRODUCTION

During the operation phase of many engineering systems, a considerable number of problems, faults, incidents and accidents can occur leading to direct and indirect consequences ranging from citizen complaints and increased operational cost to human lives losses and possibly to disasters. In order to retain an operation mode that is considered "normal" the engineers are using models and techniques from a wide range of principals like risk and barrier analysis, cognitive analysis, psychology, ergonomics, computer-human interaction, etc. They are aiming to design better and safer facilities and proper operating procedures to minimize the number of accidents and harmful-contact incidents. However, during the operation stage of many engineering systems, the timely warning and response of imminent problems is more desirable in terms of economic, political, environmental, and human resources than to deal with the outbreak and aftermath in an ad-hoc manner. Thus facilities managers and personnel have to receive and understand the signals that are transmitted by the components of the system and by the surrounding environment indicating potential occurrence of unwanted events. Based on these signals the personnel must react accordingly in order to prevent the unwanted events from occurring. In this framework, computer systems can help managers and personnel to prevent operational problems, accidents and failures by informing them about the potential unwanted event in a timely manner, by delivering a clear message to stakeholders and by providing a list of emergency response procedures.

The research goal is to develop an Early Warning System (EWS) in engineering facilities that will be able to estimate the occurrence and probability of operational problems during operations and to provide advice on how to prevent them. A high priority goal is to define the requirements and specifications of this EWS. This paper is presenting some initial results of this process. As a case study a facility has been selected that sort and process household and commercial waste. These facilities are commonly known as Material Recycling Facilities (MRFs) and are defined as: A central operation where source segregated, dry, recyclable materials are sorted, mechanically or manually to market specifications for processing into secondary materials (Gladding, Hester, Harrison, 2002). The main reason to select an engineering facility from the solid waste management sector are the statistics which have shown that the overall accident rate for the waste industry in the U.K. during 2001-2002 was estimated to be around 2,500 per 100,000 workers (HSE, 2004). This rate was about four times that year's national average. In particular, for scrap and MRFs the rates of incidents and accidents are not encouraging. In the 2004-2005 U.K. statistics of fatal injuries (HSC, 2005), the industry with the highest rate of fatal injury to employees was the recycling of waste and scrap, where the rate was approximately 27 times the national average. These statistics are revealing the size of occupational health and safety problem in the recycling industry, and point out the need for better and safer practices during the operational phase.

The MRFs are part of an overall solid waste management system. These systems are involved in a large number of accidents due to poor operational practices in each solid waste management facility. Some of them can be classified in the category of disasters. A recent example is the fire that broke out in the second larger landfill in Greece that was caused by the collapse of a large pile of waste. This fire burned for 10 days and released large amount of dioxins in the atmosphere and forced a large number of people to seek medical attention for breathing problems. The mayor requested an evacuation of the area as an emergency response but most citizens ignored the request. The result was that a large number of people ended up in the nearby hospital with breath disorders. The incident resulted in a very big scale environmental disaster.

EARLY WARNING SYSTEMS

A universal accepted definition of an EWS does not yet exist − probably one never will (Glantz, 2004). The amount of truth of this statement is significant. A literature search for EWS identifies hundred of thousands hits. Almost all of the references had to do with financial systems for third world countries, tracking the destructive nature of violent conflicts that led to human suffering, or systems for syndromic surveillance and also with human health and traffic systems for the prevention of accidents. This indicates that different perspectives of the term do exist among the scientific community.

The United Nations defines EWS as the provision of timely and effective information, through identifying institutions, that allow individuals exposed to a hazard to take action to avoid or reduce their risk and prepare for effective response (ISDR-UN, 2003). The objectives of such systems should be to provide timely warning of imminent dangers so the managers and personnel can have time to prepare and act accordingly to avoid it. The alternative is to take mitigation actions, and thus to reduce the possibility of loss of life, personal injury, damage to property and loss of efficacy. According to the literature, the four following items are the key elements of a complete and effective EWS (EWC III, 2006):

1. Risk Knowledge
2. Monitoring and Warning Service
3. Dissemination and Communication
4. Response Capability

These elements are important to EWS when it comes to coping with hazardous natural phenomena like earthquakes, tsunamis, floods and droughts. Nevertheless, these elements can be used as a guide for the design and development of EWS dealing with problems and accidents during the operations of engineering systems.

The FAST early warning project (Krummenacher, Schwarz, Siegfried, 2002) discussed the need for both qualitative and quantitative methods for specifying the information requirements of an EWS. The qualitative elements included the application of constant monitoring of events and developments, local information networks, international expert networks and fact-finding missions. The quantitative method the FAST program used was event-data analysis. Automated event-data analysis promotes timely evaluation of information provided by sensors. Since the target of our EWS is an engineering system, the event-data analysis technique is more appropriate for our research.

One of the key elements of an EWS is to provide an actual early warning to the workers, citizens, first responders, health and rescue, and local authorities that there is a potential problem. A number of local alert systems have been developed for municipalities. One example is the Alert DC system for the Washington, DC area. Alert DC is an emergency communication system developed by the D.C. Emergency Management Agency (DCEMA) to send emergency alerts, notifications and updates to end user's cell phones, pagers, Blackberry, PDAs or email accounts (Alert DC, 2006). A key feature of the Alert DC system is its ability to send text messages to individuals with cell telephones. In the event of an emergency, such as severe weather or a terrorist attack, updates and instructions can be sent a cell phone or PDA device. The figure below illustrates the systems:

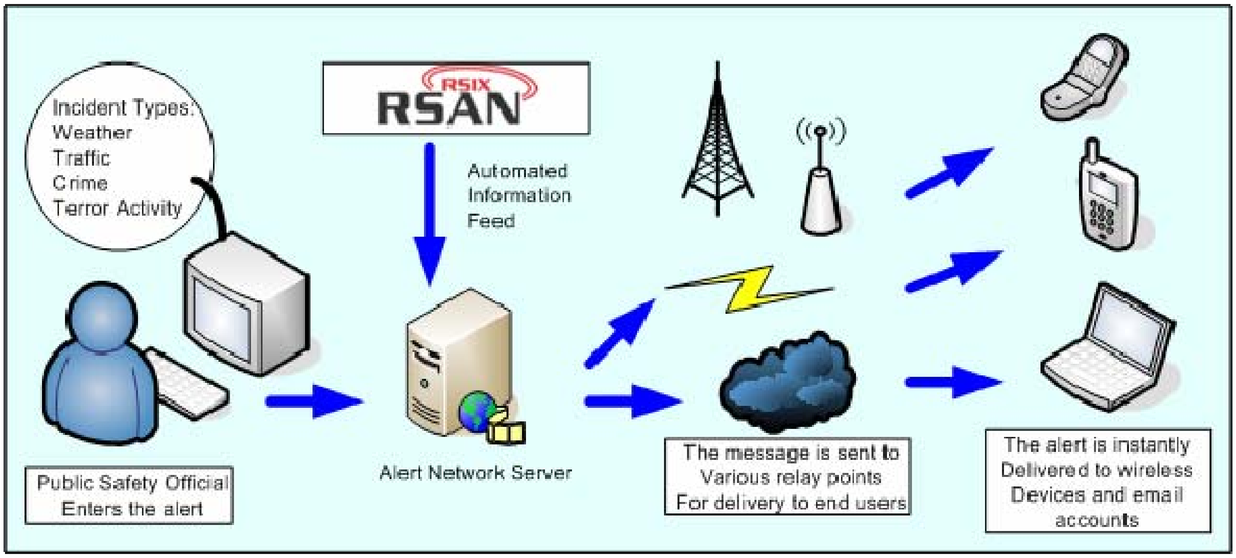

Figure 1. The Alert DC Emergency Warning System

Based on the research conducted, we developed an abstract view of an EWS. An EWS consists of sensors, or an array of sensors, computing resources and an alert mechanism. The sensors can be mechanical, electronic, chemical/biological or human. Humans act as sensor when they collect data for processing downstream.

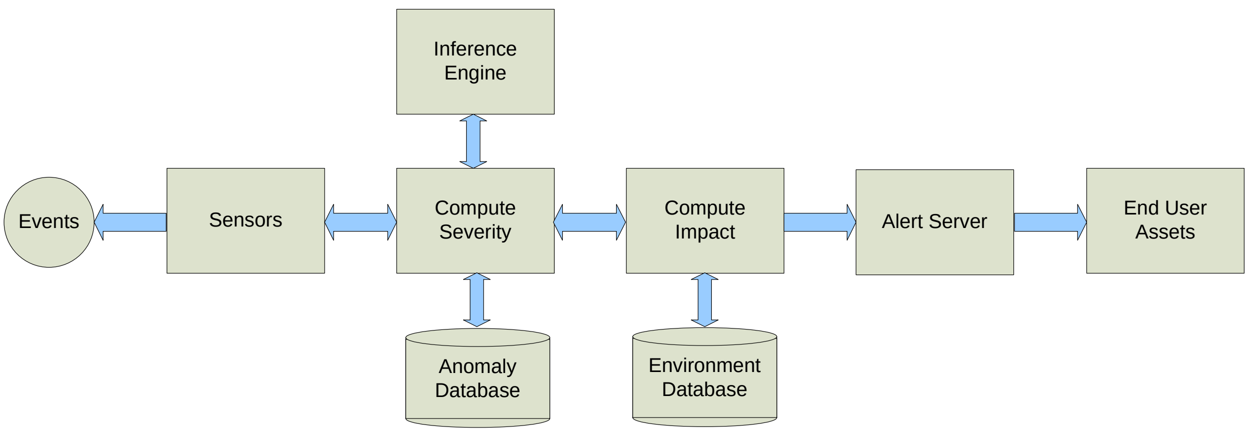

Figure 2. Abstract View of an Early Warning System

As illustrated in Figure 2, there are several elements for the computing resources, they include:

- Interpretation of the raw data. A chemical or biological sensor will collect the data and determine the chemical or biological makeup of the source.
- Compute the severity of the incident. For instance, if an earthquake occurs there are multiple facilities that collect the shock wave data and jointly determine the magnitude and location of the event.
- Compute the local or regional impact of the incident. In the event of a chemical or nuclear material release there are tools that can be employed to determine the plume, given the current weather conditions, and predict areas of impact and severity of the incidents.
- Inference engines. There is a growing area of research in syndromic analysis. This type of analysis is temporal and is intended to determine the effects of incidents over longer time periods.

- Anomaly or environment databases. Customized databases are used to support EWS, depending on the sensor arrays, location and technology innovation (such and GIS systems and population databases).

RESEARCH GOALS

The ultimate goal is to develop an EWS for a MRF. This work fits into the phase of analysis and modeling of EWS development process. This phase precedes the phase of implementation and programming. Thus, the issue of representation of the specified models that are shown in this work in to the system level of the EWS, by the use of programming languages, is not the goal of this paper but it is the goal of a future research paper. In addition, this

In this paper we are demonstrating and we are establishing a novel way on how to combine two different but specified modeling technologies, namely the IDEF0 and EXPRESS technologies, in the context of EWS modeling. In that sense we are defining the specifications of how to “configure” technologies during the next EWS development phases, which will allow us for example to control and to enable the connection, communication, and data transfer between the sensors computers endpoints of the EWS using for example specified protocols like the Common Alerting Protocol (OPEN). Basically, we are proposing the use of IDEF0 models to accomplish two things. First, we use this modeling technique to define the “as-is” view of the MRF. This tells us how the facility is operating. The model was developed from the perspective of the owner/operator of the MRF. This method allows us to see the activities that are taking place in the facility and the flow of information and materials within the plant. If we were to actually visit a facility and do this with the operators we could identify areas were there are hazardous situations and make suggestions for improvement − this would represent the “to-be” view.

The second use of the IDEF0 modeling is that it provides a framework for creating a specification, in EXPRESS, for the design of the EWS. Working in concert with a MRF we would use the IDEF0 model, which could be tailored to a specific facility. This view could be expanded to a municipality where the city is responsible for its own solid waste management system. In this case, the solid waste management system would include a number of collection trucks, some solid waste treatment facilities like MRFs and incinerators and finally some waste disposal facilities like landfills.

Although we only modeled a MRF, the EWS could be expanded for a metropolitan city where SWM operations are controlled and managed by the city. An example scenario of this case follows. In the city hall a control room is established that receives information from and submits information to all the facilities of the solid waste management system. Each facility has its own EWS for its operations. Each system can be used by the manager of the facility. The system in each facility can receive real time data from a set of sensors but also will be able to request some extra information from the manager (i.e. information that can not be measured by the sensors like the performance of an employee or if the waste collection workers are on strike, etc.).

When it receives the information from the manager the EWS of the facility will be able to search a knowledge base and explain what could go wrong based on the current working conditions. This information will be transmitted to the facility manager but also to the control center. The control center would receive the information from the facilities of the solid waste management system. Thus the control room will have a general perspective of what could go wrong in the entire solid waste management system. The control center would be equipped with a computer system that after the collection of the transmitted information, it would be able to evaluate and forecast the potentially hazardous events of the system and their respective magnitude. In case that the magnitude is above an acceptable level it will be able to transmit, after having a permission from the manager of the control room, early warning signal to the entire system (i.e., facility managers, personnel, agents, etc.), to other authorities and would be able also to deliver an emergency response plan to the manager of the control room and to facilities managers.

MODELING METHODOLOGY

We looked at a number of modeling methodologies (Noran), such as UML, Business Process Modeling Notation (BPMN, 2006) and IDEF. The combination of IDEF0 and information modeling proved to be a promising combination for defining the current engineering process and specifying the rules and constrains of EWS.

We chose IDEF0 modeling as our mechanism for capturing and defining requirements. IDEF0 is a method designed to model the activities, decisions and actions of an organization or system (FIPS, 1993). The Structured Analysis and Design Technique (SADT) formed the basis of the IDEF0 methodology. The United States Air Force commissioned the developers of SADT to develop a function modeling method for analyzing and communicating the functional perspective of a system.

In the 1970s, the Department of Defense funded the U.S. Air Force Program for Integrated Computer Aided Manufacturing (ICAM), which sought to increase manufacturing productivity through rigorous application of computer technology. The ICAM program highlighted the need for better communication and analysis techniques for individuals involved in improving manufacturing productivity (FIPS, 1993).

As a result, the ICAM program developed a series of techniques known as the IDEF (ICAM Definition) techniques which included the following:

- IDEF0 is used to produce a "function model." A function model is a structured representation of the functions, activities or processes within the modeled system or subject area.
- IDEF1 is used to produce an "information model." An information model represents the structure and semantics of information within the modeled system or subject area.

The U.S. Air Force Integrated Information Support System program, in 1983, enhanced the IDEF1 information modeling technique to form IDEF1X (IDEF1 Extended), a semantic data modeling technique. There are other semantic data modeling techniques such as EXPRESS (ISO, 1994) which we used on this project.

Currently, IDEF0 and IDEF1X techniques are widely used in the U.S. government, industrial and commercial sectors, supporting modeling efforts for a wide range of enterprise and application domains.

Effective IDEF0 models help organize the analysis of a system and promote good communication between the analyst and the domain expert. IDEF0 is useful in establishing the scope of an analysis, especially for a functional analysis. The optimal use of this method allows the domain expert to work in concert with the modeling expert to develop the best possible models. The IDEF0 enhances domain expert involvement and consensus decision-making through simplified flow diagram models. As an analysis tool, IDEF0 assists the modeler in identifying what functions are performed, what is needed to perform those functions, what the current system does right, and what the current system does wrong. The information flows, represented by arrows between activity boxes, allows the analyst to identify critics information exchange. Thus, IDEF0 models are often created as one of the first tasks of a system development effort, or are employed during a process improvement or process redesign activity.

Features of IDEF0 Modeling

The IDEF0 modeling method has proven effective in detailing the system activities for function modeling, which was the original structured analysis communication goal for IDEF0. Activities can be described by their Inputs, Controls, Outputs, and Mechanisms (ICOMs), see Figure 3. Additionally, the description of the activities of a system can be easily refined into greater and greater detail until the model is as descriptive as necessary for the decision-making task at hand. One of the observed problems with IDEF0 models is that they often are so concise that they are understandable only if the reader is a domain expert or has participated in the model development.

The hierarchical nature of IDEF0 facilitates the ability to construct "as-is" models that have a top-down representation and interpretation, but which are based on a bottom-up analysis process. Beginning with raw data, which is generated as a result of interviews with domain experts, the modeler starts grouping together activities that are closely related or functionally similar. Through this grouping process, the hierarchy emerges. If an enterprise's functional architecture is being designed, referred to as "to-be" modeling, top-down construction is usually more appropriate. Beginning with the top-most activity, the to-be enterprise can be described via a logical decomposition. The process can be continued recursively to the desired level of detail. When an existing enterprise is being, observed activities can be described and then combined into a higher level activity, which is know as the as-is modeling. This process also continues until the highest level activity has been described.

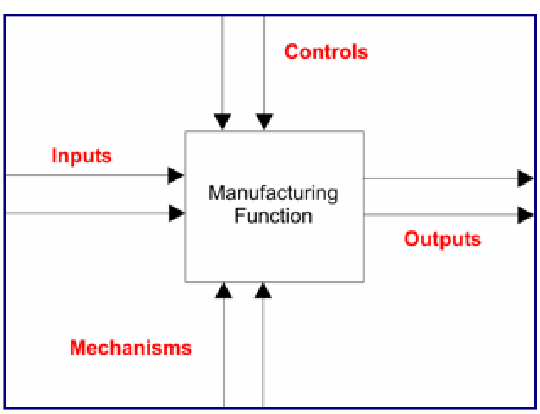

Figure 3: Basic ICOM Model

One problem with IDEF0 is the tendency of IDEF0 models to be interpreted as representing a sequence of activities. While IDEF0 is not intended to be used for modeling activity sequences, it can be applied that way. The activities may be placed in a left to right sequence within a decomposition and connected with the physical or information flows. It is natural to order the activities left to right because, if one activity outputs a concept that is used as input by another activity, drawing the activity boxes and concept connections is clearer. Thus, without intent, activity sequencing can be imbedded in the IDEF0 model. In cases where activity sequences are not included in the model, readers of the model may be tempted to add such an interpretation. This anomalous situation could be considered a weakness of IDEF0.

However, to modify it would result in the debasement of the basic principles on which IDEF0 is based and hence would lose the proven benefits of the methodology. The abstraction away from timing, sequencing, and decision logic allows succinctness in an IDEF0 model. However, such abstraction also leads to comprehension difficulties among readers outside the domain.

IDEF0 Model of Material Recycling Facilities

The IDEF0 model was developed from the owner/operator's perspective. The high level view of the model is illustrated below:

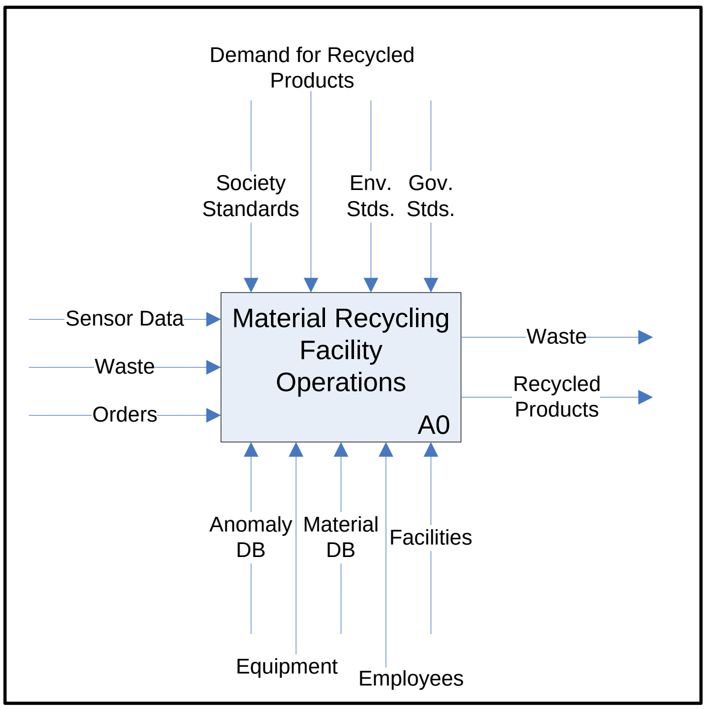

Figure 4. High-level IDEF0 View of the MRF

To understand our domain and scope of our problem, we developed the high level model. Once bounded, review of IDEF0 models allowed us to decompose the activities of the MRF. The IDEF0 model also identified the information flows between the activities. These information flows are integral to understanding critical elements for the safety and security of the MRF, including understanding the components needed for an EWS.

We decomposed the model into the activities of operations, transportation, processing, storage and disposal. From there we decomposed each of the activities to get a clearer understanding of the functions and the related information that passed between them.

The third level of decomposition elucidated a framework for understanding the MRF key operational elements. The IDEF0 model helped:

- Identify critical assets
- Identify critical functions
- Understand critical infrastructures and interdependencies

- Identify existing countermeasures
- Understand consequences

The as-is IDEF0 Process Activity model is shown in Figure 5, where the activities providing treatment to the incoming waste stream coming into the MRF are displayed with the box shape. The outputs of each one of the first four activities are the mixed recyclables which are proceeding for further treatment and waste that goes out of the system, so that to be disposed of into a landfill. The output of fifth activity are only the recyclables types which can be sold, such as aluminum cans, cardboard, glass PE/PET containers and the rest are waste. At the last activity each type of recyclable are compressed and bind by bailers. In order to establish a framework for specifying the EWS, we had to understand the information flows between the activities, and interfaces outside of the MRF functions. Since this represents the as-is view, the MRF does not have an EWS. Working with the MRF operators, we could make suggestions to improve the current operation by placing sensors and processors on the most safety critical functions. This provides us with a framework for developing a specification for an EWS for a MRF. Hence, we would propose a to-be model that would be supportive of an embedded EWS.

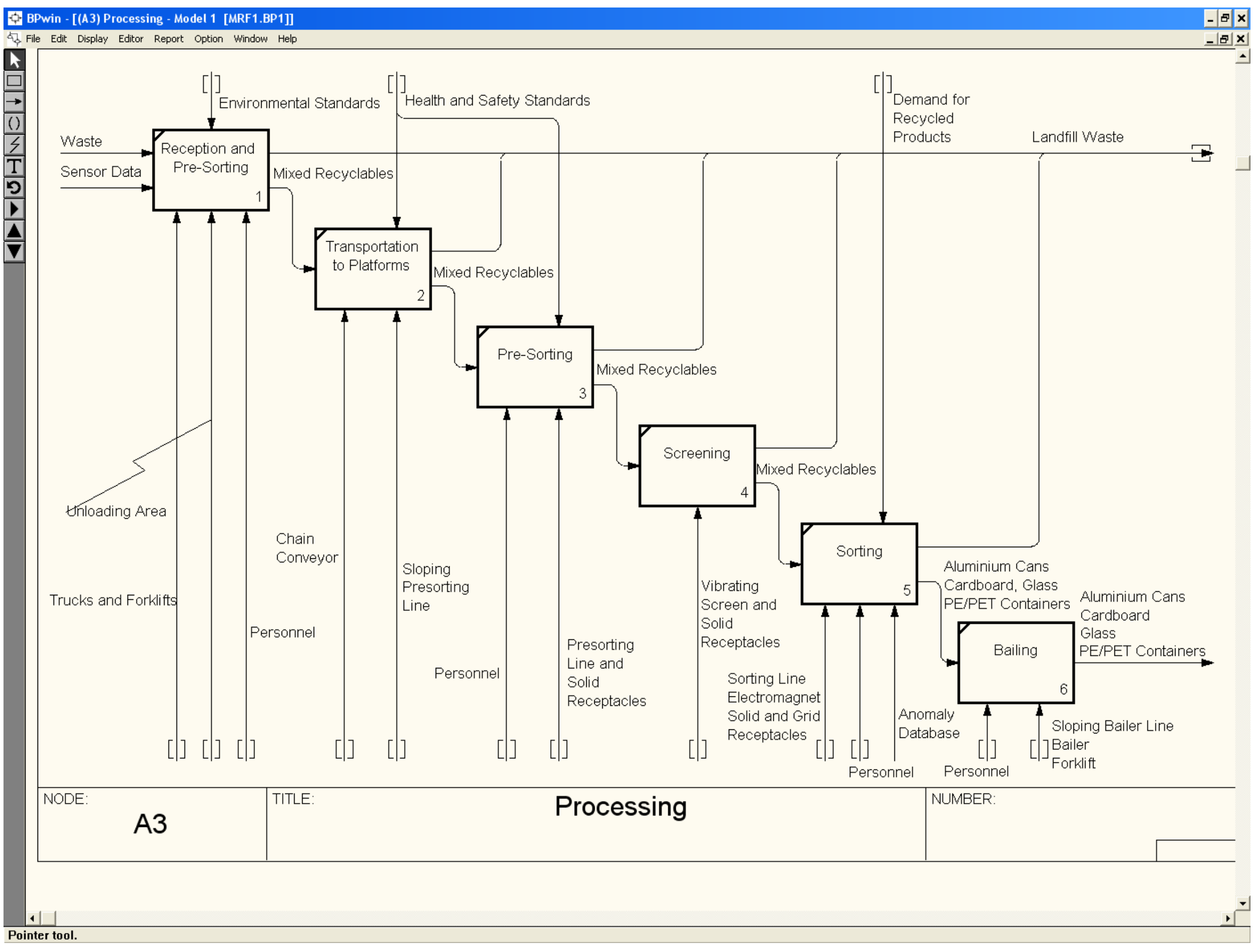

Figure 5. Third level IDEF0 model of the Processing activity.

The results of our analysis demonstrate the need for an added function, an Early Warning manager. Figure 6 represents a "to be" model that would incorporate the Early Warning manager into the above process. To make the illustration readable we did not include all of the ICOMs from Figure 5, but they are in effect for Figure 6.

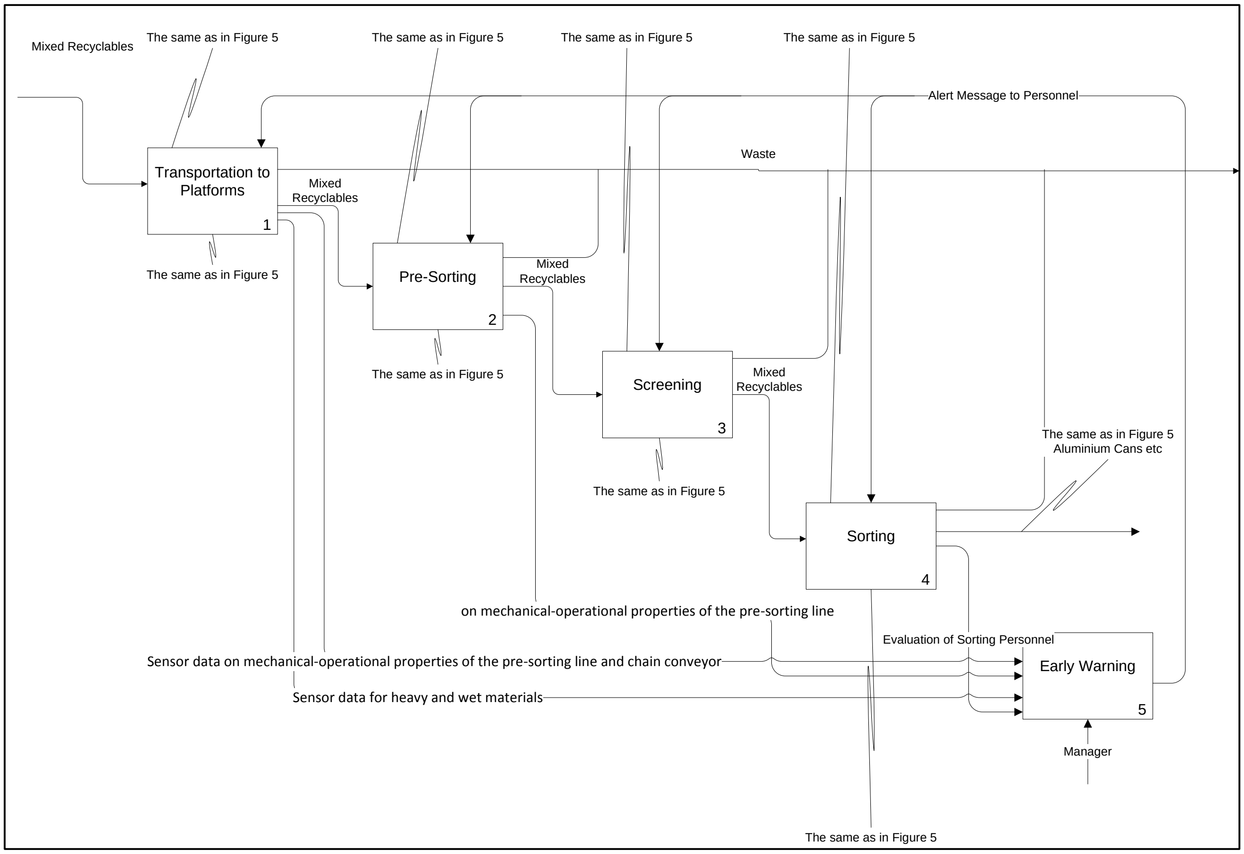

Figure 6. "To be" model incorporating the Early Warning manager.

Information Modeling

One way to collect the requirements of the EWS is through the use of information modeling (Fortier, Volk, 2006). Information modeling allows one to have an unambiguous understanding of the domain of discourse. A meta-model (schema) would be developed and the disparate information elements were turned into individual models and mapped back to the schema. Our goal would be to understand the semantic contents of the information space as requirements for an EWS.

We selected a few activities to develop information models. These models represented hazardous operations and we simulated the specification for the to-be model. Since MRF have mechanical- and computer-driven systems, we could capture real-time event data.

The major benefit of information models is that they allow rules and constraints to be applied to a domain. The result of this modeling activity would support information sharing and consistency between the mechanisms of the internal hazards, and external threats. These information models become the specification for the EWS. Also, this activity could potentially improve emergency preparedness planning.

The following code was derived from a couple of examples of alert messages. This could be a typical emergency alert message from one of the MRF functions. Multiple warnings and indication systems produce this type of information.

The information in this schema could potentially be used by the operator/owner of a MRF to monitor the function of the Sorter. The intent of this code is to provide a specification for critical information that can be collected and passed to an EWS system. This specification is generic so that it could be reused with other operating functions. This code was written in EXPRESS.

```
SCHEMA Alert;
```

```
ENTITY Sorter_Alert;
    Sent_from       : Sender;
    Stats           : Status;
    Info            : Information;
    Area            : Area_of_Interest;
END_ENTITY;
ENTITY Sender;
    Name            : STRING;
    Location        : STRING;
END_ENTITY;
ENTITY Status;
    Actual          : BOOLEAN;
    Drill           : STRING;
    Training        : STRING;
END_ENTITY;
ENTITY Information;
    Category        : STRING;
    Extent          : STRING;
    Urgency         : STRING;
    Severity        : LMH;
    Certainty       : STRING;
    Description     : STRING;
    Instruction     : STRING;
    Parameters      : GYOR;
END_ENTITY;
ENTITY LMH;
    Low             : BOOLEAN;
    Medium          : BOOLEAN;
    High            : BOOLEAN;
END_ENTITY;
ENTITY GYOR;
    Green           : BOOLEAN;
    Yellow          : BOOLEAN;
    Orange          : BOOLEAN;
    Red             : BOOLEAN;
END_ENTITY;
ENTITY Area_of_Interest;
    Longitude       : REAL;
    Latitude        : REAL;
    Description     : STRING;
END_ENTITY;
END_SCHEMA;
```

The Alert Schema is an example of a specification for an alert message coming from within the MRF. Similar specifications could be created external to the MRF and guided by the knowledge learned by developing the IDEF0 model. In essence, we would develop and collect all of these "modelettes" and the sum of them would be a specification for the EWS.

CONCLUSION

In conclusion, we have demonstrated that the use of IDEF0 modeling, combined with information model, would provide an excellent methodology to define a framework for creating a specification that can be considered as the basis for the development of any EWS – specifically for engineering systems, like a MRF. The next step in this research project would be to complete a "to-be" IDEF0 model at a MRF and derive a specification for an actual EWS. Eventually, we would instantiate the specification in the Common Alerting Protocol (CA), Emergency Data Exchange Language (EXDL) which is managed by the Disaster Management Open Platform for Emergency Networks (OPEN).

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