Cognitive Engineering Laboratory

Cognitive Work Analysis of the City of Toronto Municipal Winter Maintenance Program

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Glossary

Terms	Definition
Anti-icing	Anti-icing is a snow and ice control strategy used to prevent bond formation between ice and the pavement surface by spreading a chemical liquid (i.e. brine) before a storm begins.[1]
Beat	Pre-planned routes for equipment
Brine	A mix of salt and water.
De-icers (also known as salters)	De-icers are vehicles that the capability to spread rock salt (using salt spreaders).[2]
De-icing	De-icing is a strategy geared towards applying salt after snow actually sticks to the pavement in order to prevent the ice bond to the road surface.[3]
Graders	A grader is a vehicle with a large blade used to move snow on a road.
highway	includes a common and public highway, street, avenue, parkway, driveway, square, place, bridge, viaduct or trestle, any part of which is intended for or used by the general public for the passage of vehicles and includes the area between the lateral property lines thereof
Inspector	Field personnel responsible for monitoring the roadway, traffic, weather, and equipment conditions.
Pre-wetting	Wetting the salt before direction application onto the roads to allow the salt to adhere to the surface better and subsequently work faster to prevent ice-pavement bond.[4]
Ready / Readying	Ready or Readying in this context refers to equipment and personnel preparation prior to a winter maintenance activity
roadway	means the part of the highway that is improved, designed or ordinarily used for vehicular traffic, but does not include the shoulder, and, where a highway includes two or more separate roadways, the term “roadway” refers to any one roadway separately and not to all of the roadways collectively[5]
Roadway	Roadway
Snow Melting Process	A form of snow removal that involves transporting the snow to snow melting equipment.
Spot operations	Performing winter maintenance activities on specific areas

[1]

[2] Salt Management Plan – Appendix H, De-icing programme, page D-7
[3] Salt Management Plan – Appendix H, Ordering De-icer Applications, page 6
[4] Salt Management Plan – Appendix H, Ordering De-icer Applications, page 7
[5] Municipal Highway Traffic Act – Subsection 1, Interpretation

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	(these activities may be custom routes or pre-planned).
Supervisors	Supervisors ensure that the winter maintenance plans are followed by organizing staff and equipment to meet winter conditions.[6]
Windrows	A windrow is a row of snow accumulated after ploughing

[6] Salt Management Plan – D-9 (paraphrased)

1. INTRODUCTION

1.1 Municipal Winter Maintenance Program

Toronto has about 5100 kilometers of roads which provide for the safe, efficient, and affordable means of surface transportation for all road users (*Salt management plan summary*2004). Torontonians rely on this roadway network throughout the year for transport to the workplace, to recreation and leisure facilities, for goods and services, and for emergency and security services. Snow and ice conditions on the road system have a dramatic impact on public safety, roadway capacity, travel time and economic costs. Transport Canada estimates that over 12,000 Canadians are killed or seriously injured in traffic accidents due to snow, sleet, or hail each year (Transport Canada, 2001). Toronto spends $62.4 million annually on the city's Municipal Winter Maintenance Program (MWMP)[7] (City of Toronto, 2005) to maintain the safety and usability of these roadways. The Toronto MWMP encompasses multiple subsystems that together, operate to maintain adequate roadway conditions during the winter season.

The MIE 1406 Cognitive Work Analysis (CWA) case study entailed applying the five phases of CWA to a complex sociotechnical system. Is Toronto's Municipal Winter Maintenance Program a suitable candidate for CWA? In order to answer this question, we identified the factors that contribute to the complexity of a system (Vicente, 1999)as they apply to the MWMP.

Large Problem Spaces – The MWMP is composed of many different elements and forces including the variables that are external to the system such as those affecting weather, traffic, road conditions and variables that are internal to the system such as balancing, preparing, and operating equipment and human resources.

Social – The MWMP is composed of many people who must work together to make the overall system function properly. The MWMP employs 1068 city staff and 536 contract staff (City of Toronto, 2005). The lines of authority that govern the MWMP also extend to various members of municipal government that are not directly involved with the day-to-day operations of the program but must be informed at elevated levels of storm severity. In addition, the MWMP must also coordinate with other districts and municipalities outside of the physical boundaries of the program.

Heterogeneous Perspective – The MWMP consists of staff from different backgrounds and disciplines from analysts (e.g. equipment engineers, policy makers, meteorologists, superintendents) to front line workers (e.g. labourers, operators, and inspectors) many of which may be contract staff or in-house staff. The diversity may bring a wealth of experience but may also encourage conflicting values. The difficulty in the social negotiation process is amplified by the presence of various unions and organizational bodies representing various groups of workers.

[7] Please note that the acronym MWMP was generated as a convenient way to describe the "system", which is the subject of this report. The use of this acronym is limited to this report and may therefore not appear in City of Toronto documentation.

Hazard – The MWMP has two major hazards to consider. Firstly, winter storms cause hazardous driving conditions for both citizens and MWMP vehicle operators. Proper clearing of the roads manages this hazard. Secondly, the MWMP activities involving salt usage may pose an environmental hazard and thus salt management must be practiced in conjunction with the "Code of Practice for Environmental Management of Road Salts" developed by Environment Canada. The main objective of the Code of Practice is to ensure environmental protection while maintaining roadway safety (*Salt management plan summary*2004).

Uncertainty – Although the advent of technology has made weather monitoring relatively accurate, there is still a level of uncertainty associated with the weather. Predictions are not 100 percent reliable and reliability diminishes over time. Workers must estimate the level of resources needed to accommodate varying weather conditions and prepare equipment and staff ahead of time. In addition, the size of the system relative to the availability of sensor data also induces uncertainty. A few measurements of weather, traffic flow and roadway conditions must frequently be extrapolated to the state of the overall system.

Disturbances – Workers carrying out the objectives of the MWMP are also responsible for dealing with unanticipated events associated with weather, traffic, and roadway conditions, as well as equipment failures, and resourcing issues. Although the level of improvisation and adaptation to contingencies varies from the top of the socio-organization down to the equipment operators and patrollers, the system as a whole must react quickly to maintain safe and passable roads for the city. The 1999 storm that overwhelmed the city is a prime example of how city authorities had to adapt to an unanticipated event. More than five million people were affected by the storm (Canadian Broadcasting Corporation, 1999). Thousands of travellers spent one of the busiest travel days of the year stranded at Toronto's Pearson International Airport. Overall, the cost of storm to the city is estimated at $70 million (Canadian Broadcasting Corporation, 1999).

Vicente described closed systems as being completely isolated from their environment and as a result, the behaviour of the system can be well understood by examining the influences that are internal to the system itself. Conversely, open systems are subject to influences (i.e. unpredictable disturbances) that are external to the system (Vicente, 1999). With open systems it is not be possible to accurately pre-identify the different flow sequences or timelines that lead to the satisfaction of the goal. Vicente was careful to note that sociotechnical systems usually lie on a continuum between open and closed systems (Vicente, 1999). The municipal winter maintenance program is both an open and closed system. The initiation of winter maintenance activities are driven by disturbances in the weather, traffic flow, changes in municipal bi-laws, and political and social pressures. Workers must adapt online in real time to disturbances that cannot possibly be foreseen by designers and analysts (Vicente, 1999)

We conclude that the Municipal Winter Maintenance Program is a complex sociotechnical system that is suitable for CWA.

1.2 Intentional versus Causal Systems

Independent of the complexity of a work system, distinctions can be made between causal and intentional systems. Causal systems are physical systems where the outcomes are tightly constrained by the laws of nature, for example chemical processing plants and electricity generation systems. Intentional systems are human-activity based systems where the outcomes cannot be predicted by the laws of nature but are instead driven by individual motivations and societal constraints (Rasmussen, 1986).

One measure of these properties of a work system is 'regularity', introduced by Rasmussen. An illustration of this concept is provided below (Rasmussen, Pejtersen, & Goodstein, 1994).

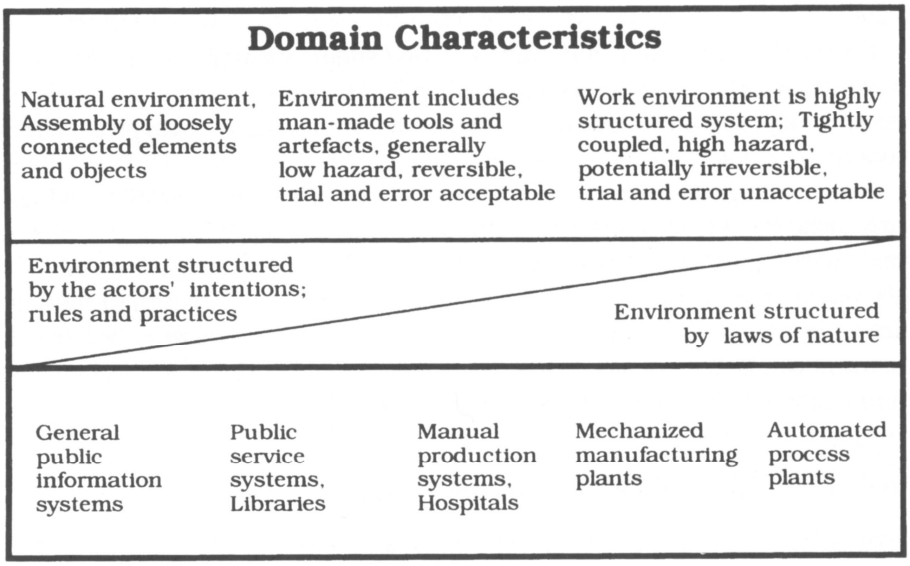

Figure 1 "Regularity" of Work Domains (Rasmussen et al., 1994)

The MWMP is constrained by many physical processes, including the natural laws with respect to salt-water mixtures, the creation of entropy (e.g. precipitation, air flow, etc…), and the conservation of momentum (i.e. traffic flow). These elements are all causal system properties. However the MWMP is also influenced by legal and societal constraints that define its purpose and measures of its success.

We can conclude is the MWMP is a mixed causal-intentional system. Comparing the relative importance of each category of constraints, the MWMP could be described by elements in the center-right of Rasmussen's continuum of intentional and causal systems.

1.3 Overview of the Phases of Analysis

CWA is divided into five phases of analysis (Vicente, 1999), which start from an ecological perspective and progress towards a cognitive perspective. Each phase identifies a new layer of constraints. The precursor, Cognitive Systems Analysis (CSA), also follows this progression, but the analysis is divided into seven phases (Rasmussen et al., 1994). The corresponding phases are compared in Table 1. The main difference lies in

the Activity Analysis, which consists of three phases or "stages of decomposition and shift of conceptual knowledge" (Rasmussen et al., 1994) Firstly, the activity analysis in *work domain terms* identifies prototypical work situations and work functions. These constrain the relevant parts of the work domain and identify the active objectives and the required resources. This CSA phase does not correspond to a CWA phase, but is rather simplified into the notion of operating modes during the CWA Control Task Analysis. Secondly, the activity analysis in *decision making terms* examines the decision functions during these prototypical work situations and functions. This analysis corresponds to the CWA Control Task Analysis, where the decision ladder is used as a modeling tool to map the "states of knowledge" and "data-processing activities" during decision tasks. Finally, the activity analysis in *cognitive terms* determines the (information processing) strategies that actors can use to accomplish these tasks. This CSA phase corresponds to the CWA Strategies Analysis.

Since the Winter Maintenance domain is a mixed intentional-causal domain, the Activity Analysis in Work Domain Terms is a critical phase in identifying work constraints and linking control tasks to the work domain. This additional phase was proven beneficial in the design of military teams (Naikar, Pearce, Drumm, & Sanderson, 2003). Typically the identified "prototypical work functions" constrain relevant parts of the work domain for known, recurring classes of situations. The "prototypical work situations" determine temporal work constraints (e.g. function A should/must be completed before function B) and are analogous to the notion of operating modes. This phase continues to narrow degrees of freedom available for action, especially in terms of intentional constraints. Therefore this phase was included in the current study and leads directly into the subsequent Control Task Analysis (CTA) since the prototypical work functions become the control tasks. Except where noted in the following sections, the other five phases in this study correspond to the five phases in CWA.

Table 1: Comparison of the phases of Cognitive Systems Analysis, Cognitive Work Analysis and the current study

Cognitive Systems Analysis	Cognitive Work Analysis	Phases in this Study
1. Work Domain Analysis (Means-ends structure of a system)	1. Work Domain Analysis	Section 2: Work Domain Analysis
2. Activity Analysis in Work Domain Terms (Task Situations)	Not Applicable	Section 3: Activity Analysis in Work Domain Terms
3. Activity Analysis in Decision Making Terms (Cognitive task)	2. Control Task Analysis	Section 4: Control Task Analysis
4. Activity Analysis in Cognitive Terms (Mental strategies which *can* be used)	3. Strategies Analysis	Section 5: Strategies Analysis
5. Division and coordination of work (Role allocation in work domain and in cognitive task) 6. Social Organization (Management style & culture)	4. Social Organization and Cooperation Analysis	Section 6: Social Organization and Cooperation Analysis
7. Cognitive resources and subjective preferences	5. Worker Competences Analysis	Section 7: Worker Competences Analysis

The following sections describe the procedure and results of the CWA, as described above. Conclusions and 'Lessons Learned' are discussed in the final section of the document.

2. WORK DOMAIN ANALYSIS

2.1 Defining the Work Domain Boundary

Before beginning the first phase of CWA, a System and Work Domain boundary must be defined. A generally accepted definition of the Work Domain is being "the System independent of any Worker, Event, Task, Goal, or Interface" (Vicente, 1999). Additionally, it is generally accepted not to include sensors as part of the Work Domain. The work domain, system boundary and elements outside of the system boundary are illustrated in Figure 2.

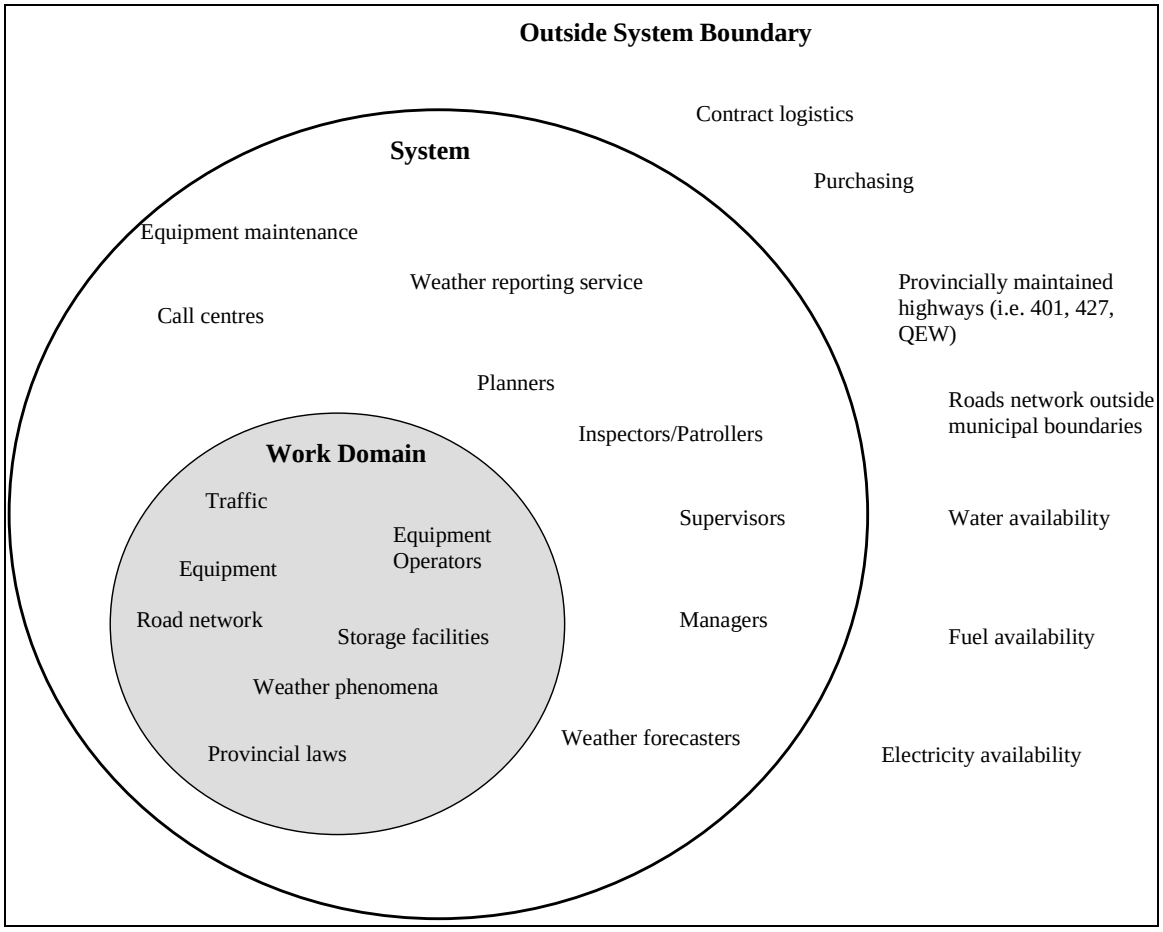

Figure 2: Work Domain and System Boundaries

The work domain and system boundaries have been defined in non-traditional ways for the following items:

> ***Inspectors and Call Centre Employees as Sensors*** - Inspectors and employees of the MWMP "Call Center" have been modeled as 'sensors' that can be used to gather observations of the state of the work domain through their activities. They

are not modeled in the Work Domain, but can be considered as part of the System.

Equipment Operators enabling functions – Equipment operators have been considered as elements of the Work Domain since they enable the functionality of other Work Domain elements such as trucks and equipment. Simultaneously, they are also considered as Workers in the system, who must generate context-conditioned variability to adapt to work effectively and respond to disturbances.

City Residents as traffic - City residents have been modeled as vehicle and pedestrian 'traffic', since it seems reasonable that interactions between residents and the snow-covered city only occur when they are traveling on the roads or sidewalks. Conversely, parked cars have been modeled as a property of roads. All vehicles have been included in the Work Domain.

2.2 Abstraction Hierarchy

2.2.1 Abstraction Hierarchy Labels

In order to develop the Abstraction Hierarchy, the levels of abstraction appropriate for the system had to be determined. The five levels of abstraction originally proposed by Rasmussen were developed for process control and manufacturing systems. These five levels may or may not be applicable to our particular system and as Vicente pointed out, although the five levels of abstraction have been useful for a variety of applications, there is no reason to believe that the same five levels of abstraction will be relevant to all work systems (Naikar, Hopcraft, & Moylan, 2005). We considered three options during the course of our work:

1) Use the traditional set of labels used for process control and causal systems (Vicente, 1999): functional purpose, abstract function, generalized function, physical function, physical form.
2) Use the set of labels suggested by Rasmussen for intentional systems: functional purposes, values and priority measures, purpose-related functions, object-related processes, and physical objects. (Naikar et al., 2005)
3) Use domain specific labels for the levels of abstraction that reflect the terminology of the work domain when presenting the Abstraction Decomposition Space (ADS) to domain experts. This approach has been successfully used in medical domains (Hajdukiewicz, Doyle, Milgram, Vicente, & Burns, 1998).

We chose not to invent new terminology to describe the levels of abstraction for the MWMP as we felt the benefits of consistency with established literature outweighed the benefits of domain specificity.[8]

[8] Should such an opportunity arise, consideration will be made to improving the language within the WDA to better suit the domain experts.

Since the MWMP system is a mixed causal-intentional system (as discussed in Section 1.2), we had to determine which of the first two labeling conventions allowed for the most consistent and psychologically relevant representation of the system.
We began by using the causal set of labels as they were more familiar to the analysts. These labels allowed the modeling of the physical processes of the system to proceed smoothly. As we investigated more of the intentional aspects of the system, we attempted to convert our AH to the intentional set of labels to benefit from the analysis suggestions in (Naikar et al., 2005). This yielded some difficulties. Firstly, the elements of the values and priorities level introduced an additional layer of intentional activity in the form of variable constraints (e.g. "Minimize salt application", "Expenditures less than budget"). This conflicted with the language and representation used to describe the physical laws. Secondly, we found the practice of associating the name of a system object with the label for the lower-most level of the AH to present a challenge in maintaining a consistent language for the second layer, the Object-related Processes (formerly Physical Function). "Functional Capabilities and limitations relating to" verbal nouns were unwieldy to manipulate in the AH format. Lastly, when we attempted to integrate the means-ends of physical mass balances and values and priority measures into a six-tiered AH, the generation of means-ends relations between levels left 'gaps' where purely natural processes had no values associated with them and hindered the representation of causal links within levels.

We therefore concluded that reverting back to the traditional set of labels produced the most useful representation of the work domain.

2.2.2 Abstraction Hierarchy

The Abstraction Hierarchy representation for the MWMP is attached in Appendix A-1. Figure 3 identifies the coverage of the Abstraction-Decomposition Space (ADS).

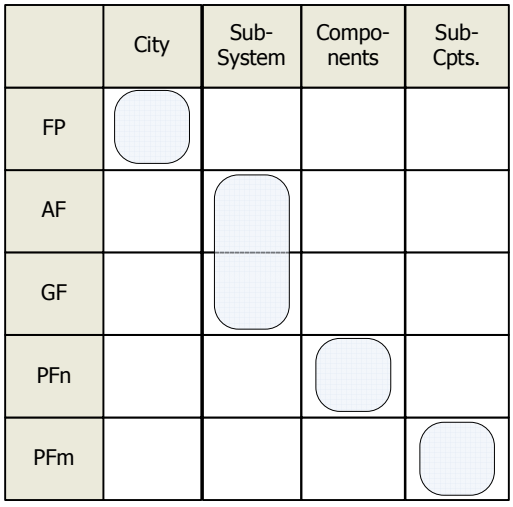

Figure 3: Abstraction Decomposition Space represented in the Abstraction Hierarchy

We discuss each entry in the first two levels of the Abstraction Hierarchy in detail below. A more general description of the more familiar Generalized Function, Physical Function, and Physical form levels is also discussed.

2.2.3 Functional Purpose

The Functional Purpose representation of the system describes the reasons for which the system exists (Vicente, 1999). Five elements were modeled, representing both causal and intentional aspects of the system. They are presented in a rough order of priority.

Maintain Safe and Passable Roads

The primary stated purpose of the MWMP is to prevent dangerous driving conditions from occurring due to snow or ice accumulation on the roadway. Collisions, injuries, or deaths attributable to poorly maintained roads have severe consequences for the municipal government. The definition of "Safe and Passable" depends on the average speed and quantity of vehicles traveling on a particular roadway. For example, a laneway accommodating a few cars at slow speeds can safely contain more snow deposits than an expressway with heavy traffic traveling at high speeds.

Minimize Impact of Weather on City Economic Activity

A secondary purpose of the MWMP is to minimize the effect of weather disturbances on the transportation activity occurring in the city. When road and pedestrian transport is slowed or prevented by snow and ice accumulation, personal, business, and municipal financial impacts can be severe. A trivial but illustrative example from the severe storms of 1999 is the $2 million in parking ticket revenues lost by the municipal government due to the economic shutdown of the city (Canadian Broadcasting Corporation, 1999).

Adhere to Municipal and Provincial Laws and Agreements

To ensure acceptable performance in the first two functional purposes across the City of Toronto and the Province of Ontario, laws have been enacted defining minimum legally acceptable levels of service (Government of Ontario, 2001). There are potentially severe consequences for failing to meet these standards, but unlike other functional purposes there are no benefits to exceeding them. While by definition this functional purpose has some overlap with others, the intentional nature of this constraint, its importance to managers and planners' decision making, and its discrete properties distinguish it from others in the Work Domain.

Remain Within a Justifiable Budget

Every municipal program must consider budgetary limitations in planning its activities. As the MWMP is open to variations in external disturbances, its budget can be expected to vary with severity of weather conditions throughout the year. Consideration of levels of service offered to components of the system that do not have major safety or economic impact such as driveway opening or suburban sidewalk ploughing are made with explicit consideration of cost (Guthrie,). From interviews with a Management level SME, P. Noehammer (personal communication, February 21, 2006), we determined that a significant portion of managerial work was devoted to writing reports to justify system expenditures.

Minimize Environmental Impact

More recently, consideration has been given to the effect of run-off from salt and other de-icing chemicals on the natural environment. Salt that escapes from the road surface leaches into roadside soil, affecting biological activity, and can contaminate groundwater if present in sufficient quantities (Environment Canada, 2004). Legislation has been enacted requiring each municipality in Ontario to implement a Salt Management Plan to encourage improvements in efficiency of salt application and new technologies such as anti-icing and pre-wetting of salt have been implemented to increase accuracy and effectiveness of salt application (*Salt management plan summary*2004).

2.2.4 Abstract Function

Elements at the Abstract Function (AF) level describe the system in terms of constraints and relationships provided by causal physical laws or intentional balances and values. Abstract Functions are means to support Functional Purposes. We identified eight subsystem elements at the AF level for the MWMP, representing a mix of causal and intentional aspects. They are discussed below in the order in which they are represented on the Abstraction Hierarchy plot in Appendix A.

Conservation, balance and flow of salt:

For the purposes of this analysis, salt is neither created nor destroyed. This element represents the balance between salt applied to the road network by MWMP vehicles and salt removed by dissolving in water and draining.

Creation of entropy:

This element describes the natural processes of increasing entropy, in particular with respect to weather phenomena.

Conservation of energy and laws governing salt-water mixtures:

Mixtures of salt and water melt and freeze at different temperatures from pure water. These phase change processes involve flow of heat energy to and from snow, air and roadway. This element represents the physical processes governing rates of phase changes in snow/salt mixtures and their relation to ambient temperatures.

Conservation, balance and flow of water forms:

Similar to the balance and flow of salt, the balance and flow of water element represents the accumulation of water forms on the roadway and road shoulder in terms of sources (precipitation and salt brine), transports (wind, snowploughing) and sinks (melting, draining and snow removal procedures).

F=ma and conservation of momentum as applied to traffic:

Safety and rate of traffic flow is strongly affected by traction of vehicle tires on the road surface. Snow and ice accumulation reduce this traction and can result in hazardous situations where vehicles cannot be safely navigated. This element represents the relationships between vehicle speeds and maneuvering capability, and the relationships between steepness of road slope and traction required.

Economic balance of city:

The municipal road network affords transportation of goods and delivery of services across every aspect of city processes. The economic relationships represented by this element support decision-making regarding costs and benefits of the MWMP.

Balance of resource needs and capabilities:

This element represents conservation of equipment capabilities and the matching of capabilities to demand. With limited equipment and personnel resources, and variable traffic and road conditions, this balance must be considered when making decisions concerning equipment dispatch and scheduling.

Balance of budget and authority:

To function within the organizational structure of the municipality, expenditures must be accounted for by managers and City Councillors. As a result, any MWMP must allow for a relation between budgetary decisions and authority figures.

2.2.5 Generalized Function

The Generalized Function (GF) level represents how elements at the Abstract Function level are achieved. This section was modeled at a sub-system level. Elements of water and salt balances are described by Melting, Freezing, Salt application, and Draining, amongst others. Elements at this level represent processes that support or are constrained by balances described at the Abstract Function level.

2.2.6 Physical Function:

Elements at the Physical Function (PFn) level include capabilities of physical elements in the System Boundary and are represented at a component level. Included are capabilities of common classes of MWMP equipment such as anti-icing trucks, snowploughs, and Snow Melting equipment. Sun, wind, snow, and other weather phenomena are described in physical capability terms.

Some indication of alternative means-ends is represented, such as the Generalized Function of “Draining” being achievable either through the Physical Function of Municipal or Environmental drainage systems. This represents conditions where if municipal drainage systems fail in some way, for example a drain grate in the roadway becoming blocked with ice and snow accumulation, the roadway will overflow and drain salt and water into the natural environment.

2.2.7 Physical Form

The Physical Form level was not modeled extensively, as it is very dependant on the details of a specific System being modeled. We believe it is most useful to consider this level of abstraction at a sub-component level. At this level the form, location and appearance of each Physical Function element would be represented. Employees would be identified by their names and appearance, vehicles would be identified by their registration numbers, model types, and roadway identified by its name and lane width.

2.3 Part-Whole Decomposition

We performed a Part-Whole (PW) Decomposition for the physical function level because we felt that it was the abstraction level that provided the most psychologically relevant elements throughout all levels of aggregation. The PW coverage is illustrated in Figure 4.

	City	Sub-System	Compo-nents	Sub-Cpts.
FP				
AF				
GF				
PFn				
PFm				

Figure 4: Abstraction Decomposition Space represented in Part-Whole Decomposition Example

The Part-Whole decomposition is presented in Appendix A-2. Decomposition and aggregation of the work domain system was carried out in four divisions:

1. ***City***: As discussed above in the System Boundary, this represents the 'whole city' level of aggregation, most useful for representing Functional Purposes
2. ***Sub-system***: Large subgroups of components such as different broad classes of equipment are decomposed at this level
3. ***Components***: Aggregation of specific instances of road forms into 'bridges' or 'sidewalks' is performed at this level
4. ***Sub-Components***: This level was not modeled at any level of detail and is intended to represent specific instances of Components, for example personnel #51241, Gloria Smith, Equipment Operator. These specifics are available from city maps, employment records, and equipment inventories

We also introduce in the in Appendix A-2 figure a convenient partitioning of the work domain into "object worlds" in the Part-Whole Decomposition example (Rasmussen et al., 1994). They are areas of the work domain that certain classes of actors typically reason within. We discuss these in more detail in the Socio-Organizational Analysis, Section 6.1.

2.4 Causal links for the work domain

As a means of refining the Work Domain model and of exploring possible control tasks, we modeled a selection of causal relations between causal elements at the Abstract Function (AF) and Generalized Function (GF) levels. Figure 5 identifies the examples covered in the ADS.

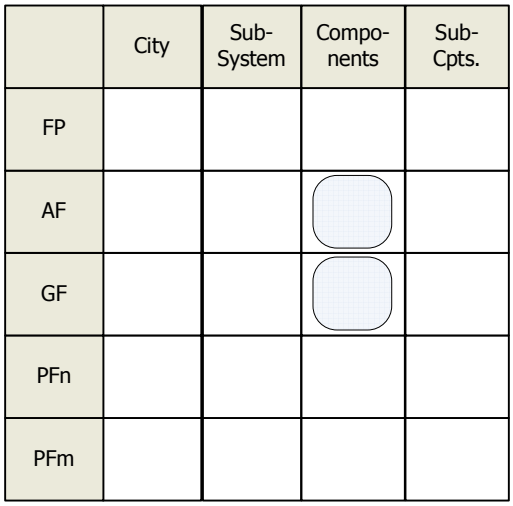

Figure 5: Abstraction Decomposition Space Represented in Causal Links Example

The causal abstraction hierarchy representations were generated to help expose relations governing several control tasks (see Section 4). Appendix A contains two causal abstraction hierarchy representations. Appendix A-3 represents an integrated salt and water mass flow and balance at the AF level and Appendix A-4 at the GF level.

The modelled causal relationships depicted in Appendix A-3 and 4 focus on physical processes of salt and water and do not incorporate city, equipment, or personnel. Also, equations governing the strength or rate of causal relationships were not investigated. Useful relationships for processes involving equipment and personnel can be illustrated through these representations. For example, the Abstract Function causal links in Appendix A-3 indicate that wind drifting can eliminate the need to melt snow to remove it from the roadway at certain periods. No salting should be performed in conditions where wind is clearing snow from roadways and depositing it in drifts on the roadway shoulder. Salting at this point will encourage melting and re-freezing and initiate snow accumulation on roadway (Transportation Services, 2005).

Important characteristics of the melting and re-freezing processes can also be illustrated with the Causal Links diagram. For example, snow that melts from the road

accumulation and flows into regions of cooler road temperatures can re-freeze before draining, which will present an severe hazard through drastically reducing grip on the road.

2.5 Work Domain Model Weaknesses

The Work Domain Model as developed is not exhaustive and contains several identified weaknesses:

- ***Accuracy of salt application*** - This model does not account for how much salt dispersed from trucks stays on the traveled portion of the roads where it is useful. It has been recognized that different application choices have different effects: pre-wetting causes salt to 'bounce' less on bare roads, for example.

- ***Multiple locations of melting/freezing*** - The freeze/thaw cycle is most worth modeling for snow on the roadway where ice can present a hazard to traffic flow. Melting and re-freezing has not been explicitly modeled for roadside snow.

- ***Stratification of snow on roads*** - A fine-grained level of detail is required to show the benefits of Anti-Icing technology. A thin layer of salt applied to the roadway before snowfall has more useful effect than the same quantity of salt strewn on top of the snow, due to the disruption of the ice-road bond.

- ***Homogeneity of snow on roads*** - The laws of salt-water mixture melting and freezing apply on a scale much finer than modeled in this analysis. Salt application and dissolving are not entirely sufficient to model these processes. Great care is taken in the existing system to ensure that salt spreaders are working properly and that mixing of salt and snow by traffic.

2.6 State Variables

An Information Availability Analysis was performed to begin to determine state variables for use in Activity Analysis and the Control Task Analysis. It is included in Appendix A-5

We subsequently aggregated the list to a subset of State Variables that we found useful to describe the state of winter maintenance operations. These were divided into categories suitable for conducting Control Task Analyses, organized along the lines of the “Object Worlds” discussed in the Socio-Organizational analysis.

Table 2: Selection of State Variables Derived from the Abstraction Hierarchy

Category	Variables
Personnel (A)	1. Available 2. Not available 3. Preparing 4. Working 5. Overtime
Storage (B)	1. Rock Salt Storage 2. Brine Storage
Equipment (C)	1. Functional 2. Non-Functional 3. Ready 4. Deployed/Activate
Road Phenomena (D)	1. Surface Temp 2. Snow accumulation 3. Ice accumulation 4. Salt accumulation 5. Car accumulation 6. Shoulder Snow Storage 7. Dump Snow Storage
Weather Phenomena (E)	1. Precipitation 2. Air Temp 3. Wind
Traffic (F)	1. Vehicle Flow 2. Pedestrian Flow

3. ACTIVITY ANALYSIS IN WORK DOMAIN TERMS

The goal of this phase of the analysis is to identify what activities need to be done in the work domain. These activities are classified into known, recurring classes of situations and are "analysed in terms of a set of problems to solve or a set of task situations to cope with" (Rasmussen et al., 1994). This phase identifies the part of the work domain that is relevant for each class of activities and identifies constraints on *what* needs to be done ("prototypical work functions") and *when* it needs to be done ("prototypical work situations"). Initially the difference between prototypical work functions and situations was that the latter are "well defined in time" but the former are not "clearly delimited in time" (Rasmussen et al., 1994). The analyst was to choose which representation was more appropriate based on the work domain, for example, work *situations* occur in hospitals (examination, hospitalization, operation, post-operative check, etc.) and work *functions* occur in manufacturing (subassembly, painting, assembly, packing, etc.).

Recently these concepts were used orthogonally during a CWA for military teams (Naikar et al., 2003). In this case, the actors participate in a set of *work situations* where they are required to solve a set of *work problems* (i.e. work functions) to fulfill the work domain constraints. The work situations were represented by the different phases of a military mission and the work problems represented what needed to be done, such as "develop SA" or "manage crew". The work problems were mapped onto work situations. This adaptation was used for the current study.

3.1 Prototypical Work Functions

Prototypical work functions include the Generalised Function processes along with supporting administrative and planning activities. Therefore the names tend to reflect the processes they represent or the language used by workers. The prototypical work functions for winter maintenance are shown in Figure 6. The single line circles represent temporally-dependent activities (Rasmussen termed these "transactional" activities) whereas the double line circles represent general, continuous activities ("resource planning"). The arrows between single line circles are similar to causal links in the abstraction hierarchy representation; they represent the sequence in which work functions must (or should) be completed. The arrows from double line circles indicate the temporal activities that these continuous activities support. The activities in the box are those that determine the current state of operation of the entire winter maintenance program. These are activated in response to storm activity.

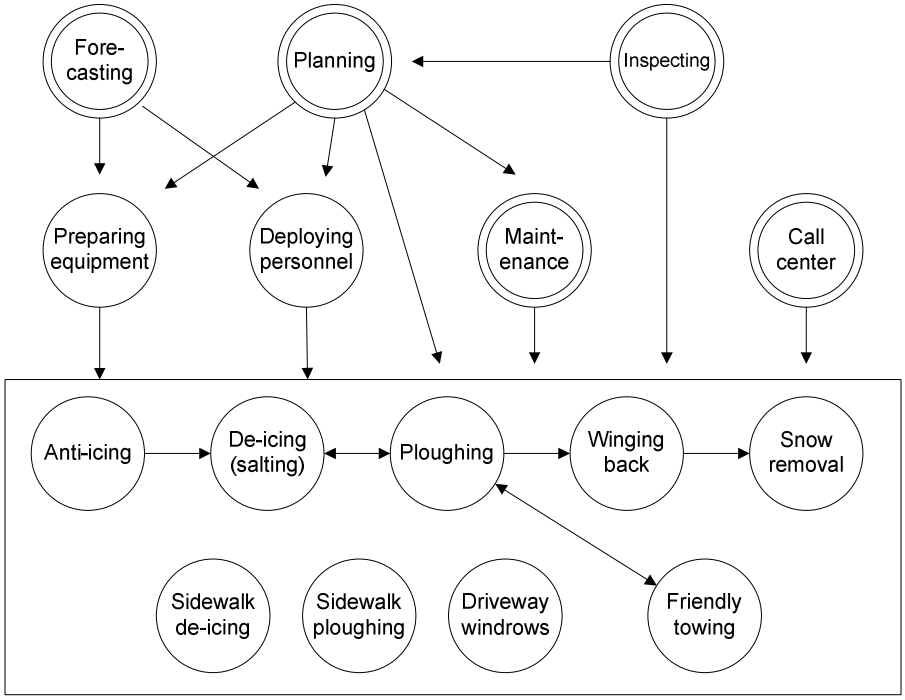

Figure 6: Prototypical Work Functions

3.2 Prototypical Work Situations

Prototypical work situations are similar to the notion of operating modes (Vicente, 1999). For winter maintenance, prototypical work situations include the preparation period leading up to a storm, the escalation of storm types during a storm, and the clean-up period following the storm. These are based on regulatory constraints (Government of Ontario, 2001)and the logical sequence of activities. Storm types were determined based on these Municipal Code stipulations of the snow accumulation level when resources are to be deployed. The post-storm situations are based on the stipulations in the code of the time periods to complete clearing of snow accumulation.

Table 3 places the prototypical work functions in the context of work situations. Dark grey represents the combinations that *should* occur, light grey represents the combinations that *could* occur (i.e. this solution may involve a trade-off of functional purposes) and white represents combinations that *should not* occur. These are cases where a constraint is violated or a functional purpose is violated. Examples of constraints affecting tasks include:

- No effective ploughing can be performed when there is less than 2cm of snow on the roadway surface.
- Anti-Icing is not possible once snow starts sticking to the roadway.
- The effectiveness of De-Icing with rock salt degrades with increasing snow accumulation and decreasing temperatures.
- Sidewalk operations are only initiated after 8 cm of snow accumulation in order to meet budgetary requirements.

Table 3: Prototypical Work functions vs. Work situations

	Work Situation									
	Pre-storm	Storm						Post-storm		
		Storm 1		Storm 2		Storm 3	Storm 4	16 Hr	20 Hr	24 Hr
Work Function	Total snow accumulation	0-2.5 cm	2.5-5 cm	5-8 cm	8-15 cm	15-25 cm	>25 cm			
Preparing Equipment Load salt & brine into trucks, calibrate trucks, etc.										
Deploying Personnel Activate operators and associate them with equipment										
Anti-Icing Break/prevent ice-road bond by spreading brine										
De-Icing Reduce accumulation by salt spreading										
Ploughing Reduce accumulation by ploughing to windrows										
Winging back Increase snow storage capacity by shifting windrows										
Snow removal Increase snow storage capacity by melting or transporting										
Sidewalk salting Reduce sidewalk accumulation by salting										
Sidewalk ploughing Reduce sidewalk accumulation by ploughing										
Driveway Windrows Allow traffic flow by shifting driveway windrows										
Friendly Towing Reduce vehicle accumulation by "Friendly Towing"										

4. CONTROL TASK ANALYSIS

The goal of the Control Task Analysis is "to identify the requirements associated with known classes of events" (Vicente, 1999). We chose a subset of the prototypical work functions in the Activity Analysis for Control Task Analysis. The tasks were selected to demonstrate the temporal constraints and cascading of prototypical work situations illustrated above and to provide a variety of presumed shunts and leaps in the mapping onto the Decision Ladder.

4.1 Modeling Commentary

4.1.1 Shunts / Leaps

As discussed elsewhere in this document, we did not have the opportunity to observe workers in their work environments and so were limited in data to back up our judgement of when shunts and leaps could be performed. We inferred from SME interviews that operations involving more cost always required more interpretation and evaluation of performance criteria (P. Noehammer, personal communication, February 21, 2006) Execution of anti-icing and the first few rounds of de-icing salt are currently performed without much consideration of functional purposes or ambiguity and were presumed to use many leaps and shunts.

Some consideration is currently given to the need or appropriate time to stop de-icing operations and begin snowploughing, since any salt distributed on the roadway will be ploughed to the shoulder with consequent need for more salt and for environmental impact. Operations such as snow removal involve an order of magnitude higher cost than snowploughing, and therefore involve significantly more ambiguity and conflict between functional purposes. Current practices require consultation and escalation of authority in decision-making when initiating such costly procedures, reflected in this analysis by a reduction in shunts and leaps (Transportation Services, 2005).

4.1.2 Grain of Analysis

The prototypical work functions are modeled at a relatively coarse-grain level of analysis. For example, the 'Execute' step in the Decision ladder can represent a decision maker coordinating actions of other workers or could in itself be modelled as a decision ladder for another worker.

4.1.3 Multiple Loops vs. Multiple Ladders

Readying consists of the prototypical work functions "deploying personnel" and "preparing equipment" (Figure 6). The other temporally dependent activities (identified in the 'state of operations' box found in Figure 6) will each require elements of readying.

For our modeling purposes, we considered two possible representations: The first representation uses several Decision Ladders, at a minimum one for the core elements of each 'state of operation' work function, and one for readying procedures common to several of the other work functions (Rasmussen et al., 1994). This has the advantage of re-use of modeling diagrams, but does not allow any idiosyncrasies in the readying

procedure to be tailored for different 'state of operation' work functions without diagrams becoming too complex. The second representation involves multiple 'loops' through the Decision Ladder, in which each information processing activity can involve different aspects of the work domain (Vicente, 1999). For example, when looping multiple times around the ladder, the "execute" box will represent first readying and next deploying. Likewise, the "knowledge of observations" circle will represent different observations needed for different loops around the decision ladder.

The second 'multiple-loop' representation was chosen as it can more consistently represent the cycles of control tasks observed in the MWMP. Loops are represented by the use of different line types for the arrows, and transitions between 'loops' are marked.

4.2 Decision Ladders

The following four prototypical work functions were analyzed in this section as control tasks:

1. Anti-Icing (brine application)
2. De-Icing (salt application)
3. Snowploughing
4. 'Friendly Towing' (parked car relocation)

Decision Ladder representations for all control tasks are included below and attached in Appendix B.

4.2.1 Anti-Icing

Anti-icing is, when possible, the first control task performed in anticipation of a weather event. An activation signal of some kind alerts the operator to the probability of a snow or freezing rain event. If this activation is received with enough advance warning, anti-icing can be performed. The Decision Ladder for Anti-Icing is illustrated in Figure 7 below.

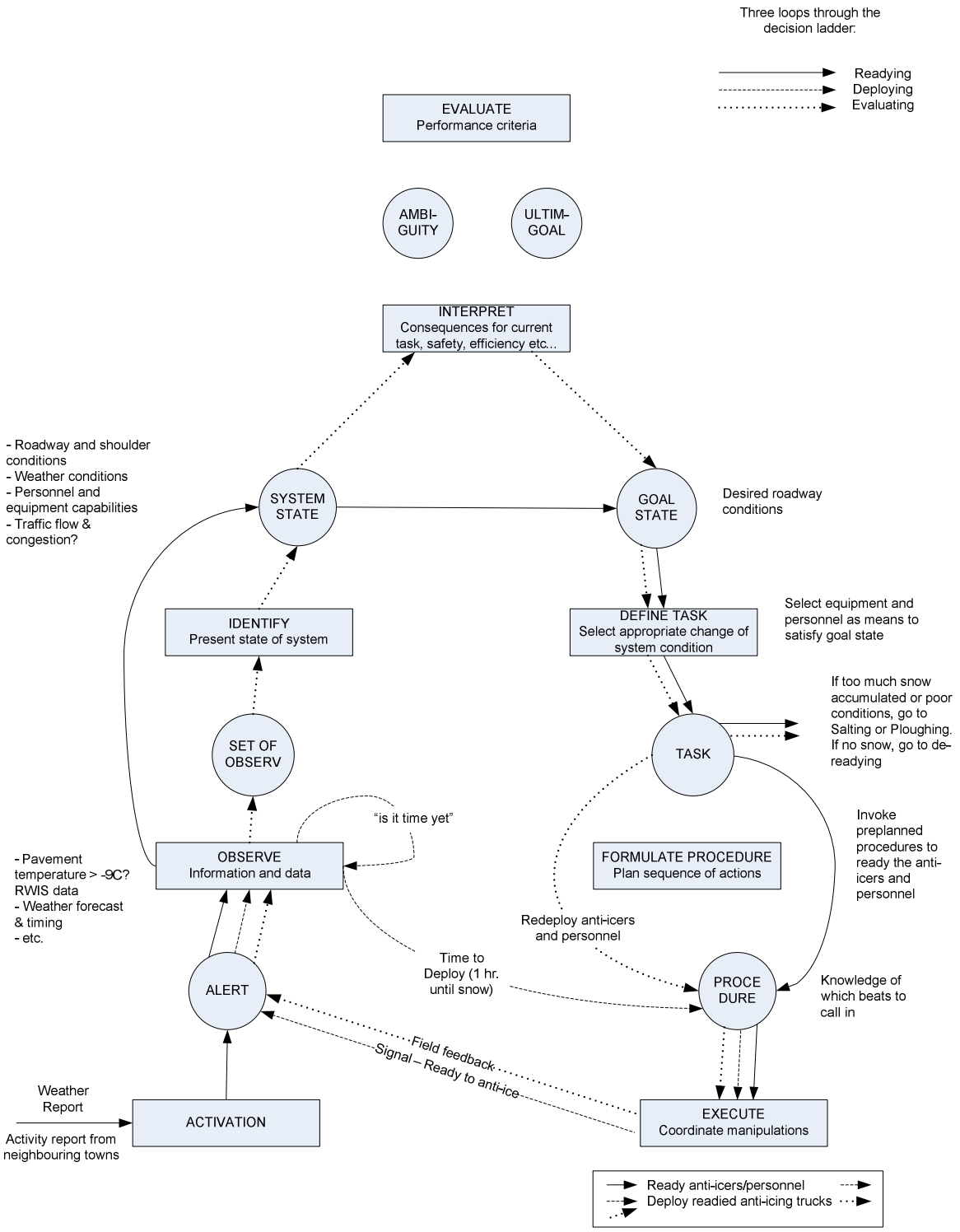

Figure 7: Decision Ladder for Anti-Icing control task

Observation of the current and future weather conditions to identify the air and pavement temperatures will indicate if an accumulation of snow or ice will occur. Pavement temperature is the most important variable, as snow falling in +1C air temperature on a -1C road will freeze and create unsafe driving conditions. If there is already a layer of salt on the road from a previous application, anti-icing may not need to be performed. Availability of personnel and equipment must also be observed to determine what time delays will be associated with their readying. Time of day and current traffic conditions must also be observed, as they are associated with delays in deployment. All are typically observed without extensive consideration of 'what lies behind', since the recurring class of anti-icing activities starts with bare roadways, a system state of reduced uncertainty that is more easily associated with observations.

Depending on if the System conditions are appropriate for anti-icing and equipment is available, the Goal State of the system can be determined and a task formulated. This change in system condition may not be for a layer of anti-icer to be applied. If snow will be falling too soon, or conditions are too cold, or pavement is not bare, then salting or plowing may be the appropriate task.

Task knowledge is often linked directly with knowledge of the procedure to accomplish it. As discussed below, pre-planned equipment routes are available for every section of the city, including complete main road coverage or 'trouble spot' coverage of hills and bridges depending on the anticipated weather.

Once a procedure has been determined, the appropriate equipment and personnel must be readied for action. This involves a certain delay depending on the state of the personnel and equipment and the state of the traffic flow and car accumulation in the system. Once equipment and crews are on 'stand-by' near their assigned roadways, deploying must be delayed until an observation is made that the weather incident is approximately 1 hour away. This is due to physical constraints regarding anti-icer draining and dissolving rates.

Once the anti-icers are deployed, a more in-depth evaluation of the system is performed in response to feedback from equipment operators and continued monitoring of the weather conditions. If the weather precipitation continues or temperatures drop, salting or ploughing is the next step. If the weather system is delayed but still likely to occur, the anti-icers may be redeployed.

Rarely are ambiguities and interpretations about anti-icing considered at the highest levels of the Decision Ladder. The cost of the operation is not great, and weather events recur frequently enough that the decision making process is routine.

Table 4 lists the state variables associated with the data processing and decision making processes for the Anti-Icing control task.

Table 4: Summary of State Variables for the Anti-Icing Decision Ladder

Loop	From → To	State Variables
Readying	Activation →Alert	E-1 Precipitation
	Observe →System State	A-1 Available Personnel B-2 Brine Storage C-1 Functional Equipment D-1 Road Surface Temperature D-2 Snow Accumulation D-3 Ice Accumulation D-4 Salt Accumulation E Weather Phenomena F-1 Vehicle Flow
	Define Task → Task	A-1 Available Personnel B-2 Brine Storage C-1 Functional Equipment
	Execute → Alert	A-3 Personnel Preparing
Deploying	Observe → Observe	A-4 Personnel Working C-3 Equipment Ready D-1 Road Temperature E Weather Phenomena
	Observe → Procedure	E-1 Precipitation E-3 Wind
Evaluating	Execute → Alert	A-4 Personnel Working C-4 Equipment Deployed
	Observe → Set of Observations	A-4 Personnel Working B-2 Brine Storage C-4 Equipment Deployed D-1 Surface Temperature D-2 Snow Accumulation D-3 Ice Accumulation D-4 Salt Accumulation E Weather Phenomena F-1 Vehicle Flow
	Identify → System State	Same as above
	Define Task → Task	A-4 Personnel Working B-2 Brine Storage C-4 Equipment Deployed D-2 Snow Accumulation D-3 Ice Accumulation D-4 Salt Accumulation

4.2.2 De-Icing

De-Icing has a similar structure to the Anti-Icing decision ladder, with some modifications. The De-Icing work function can be initiated either by weather reports and inspectors' observations or by a determination of a new task during anti-icing actitivies. The De-Icing decision ladder is shown in Figure 8 below.

A decision to begin a first round of salt is made without extensive consideration as shown by the leap between observations and task knowledge. An actual or forecasted snow accumulation on the roadway and a temperature of below 0C and above -20C are the primary roadway and weather indications that salting will be required. Equipment and personnel must also be available. As with Anti-icing, pre-planned procedures are extensively used, especially for the first round of salt coverage. Delaying dispatch of the first round of salt can have negative consequences, as the physical processes of salt-snow mixtures result in reduced melting ability when salt is applied on top of snow accumulation rather than underneath.

After salting personnel are readying with their equipment, a timing decision must be made by the operator. As shown in the causal Work Domain links in Section 2.4, snow can be removed from roads by drifting due to wind action as long as there is no salt on the roads to begin melting and cause snow to accumulate. Readied crews can thus be delayed until roadway snow accumulation actually begins, resulting in a savings in salt requirements.

Once snow accumulation begins, trucks and drivers are deployed. Field feedback on changing road conditions is relayed by drivers, and a more thorough examination of the work domain is performed to determine the extent of salting that is required. Tasks that can be considered are:

- To continue to apply salt throughout the city. This would be an appropriate decision if the predicted snow accumulation is small (<5cm) and will cease shortly.
- To de-mobilize most salting crews and send a reduced number of personnel and trucks to perform 'spot-salting' of problem areas. This would be an appropriate decision if the snow accumulation has stopped and if melting is proceeding in most locations.
- To ready snowplowing personnel and equipment. This would be an appropriate decision if the snow accumulation is predicted to continue and be large enough to reduce the economy and efficacy of salt.
- To de-mobilize all personnel and equipment.

The subject matter expert has indicated that up to two re-deployments of pre-planned routes is often considered as the economic and environmental balance point between salt application and ploughing (P. Noehammer, personal communication, February 21, 2006). Decision-making regarding when to switch tasks is one of the core components of this control task.

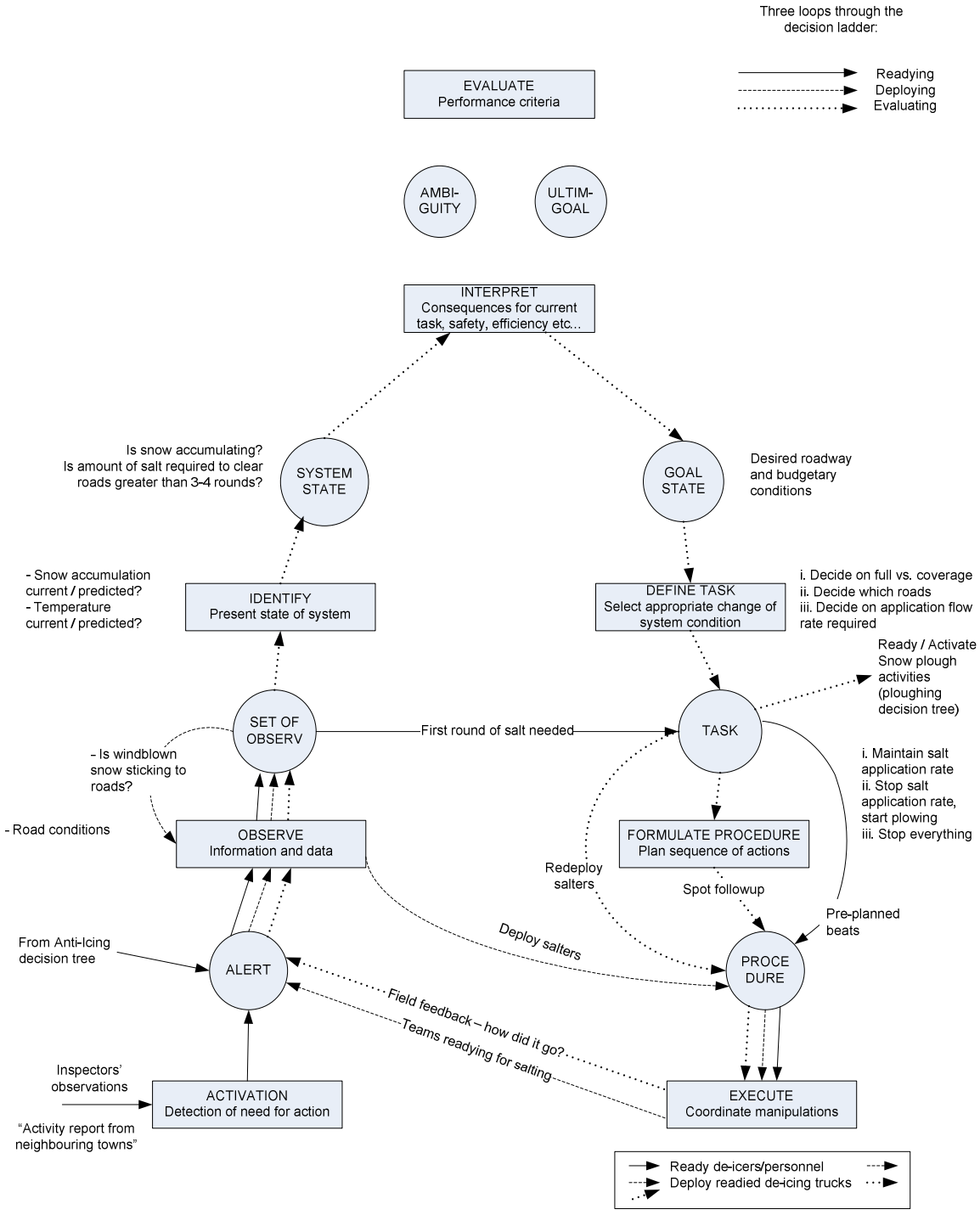

Figure 8: Decision Ladder for De-Icing control task

4.2.3 Snowploughing

Snowploughing work functions are similar in procedure to de-icing, but without many of the weather and salt-water mixture work domain constraints. Ploughing has no dependency on road or air temperature and does not consume salt. Because of this, ploughs can be deployed under any weather circumstances without concern for freezing of salt-water mixtures. They can also be deployed without consideration of the functional purpose of minimizing environmental impact. Ploughs can also be deployed without requirements for periodic re-loading of rock salt or brine, although they are still constrained by the employees' salary and shift work limitations.

System state variables that are of interest to decision makers in a snowploughing situation are the level of snow accumulation on the roadway and the level of storage on the roadway shoulder.

Ploughs have a capability limitation in that they can only reduce the level of snow accumulation on roadways to 2cm due to the requirement to raise plough blades on 'shoes' in the rough roads of urban environments. This means that there is always residual snow left on the roadways. If weather conditions do not facilitate melting, then de-icing must follow the last deployment of ploughs.

Conversely, if snow accumulation exceeds the the ploughs' capabilities to push snow onto the road shoulders, then specially equipped 'winging back' ploughs must be deployed to shift snow windrows further away from curbside. If snow accumulation is predicted to exceed the road capability to store snow, then Snow Removal operations must be considered. These operations are extremely expensive (P. Noehammer, personal communication, February 21, 2006) and will be expected to involve significant iteration between ambiguity and ultimate goals.

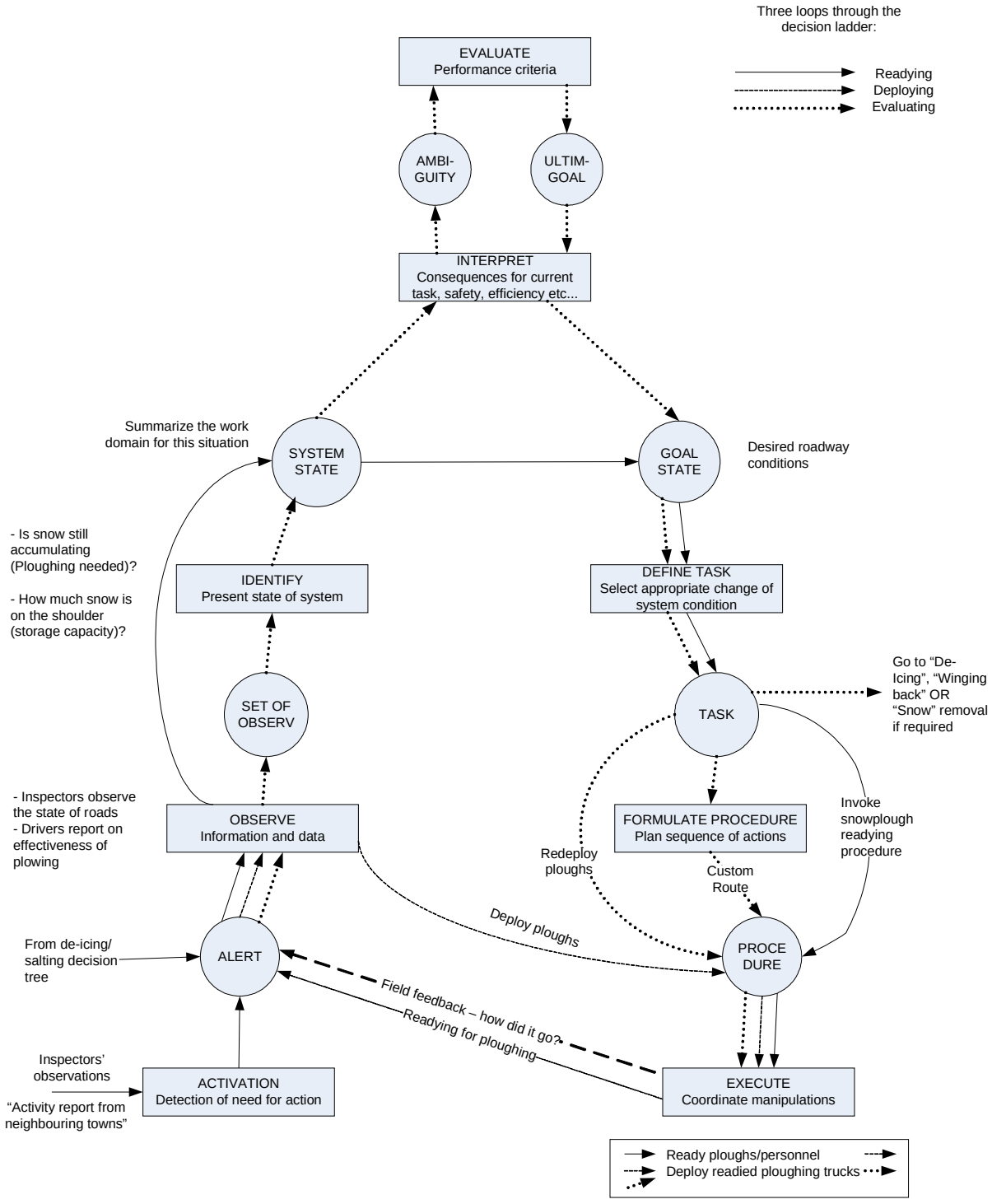

Figure 9: Decision Ladder for Snowploughing control task

4.2.4 Friendly Towing

During snowploughing operations, parked car accumulation at the roadside can negatively affect the outcome of work due to the snowploughs' limited capability to manoeuvre and their limitations of continuous ploughing of snow. Large snow windrows impede traffic flow and remain even after the car owner removes their vehicle. Therefore it is sometimes economical to employ towing equipment to relocate parked cars so that ploughing processes can move snow accumulation to the roadside.

This decision tree shows a requirement for interpretation and evaluation on the first loop through the decision ladder due to the large cost in personnel time to execute this operation. An anticipated exception is if a car is completely preventing a snowplough from clearing a main road of large economic value to the city transportation and with a large potential for safety concerns.

Due to its high cost, Friendly Towing is often not employed on a city-wide basis, so pre-planned procedures are not used.

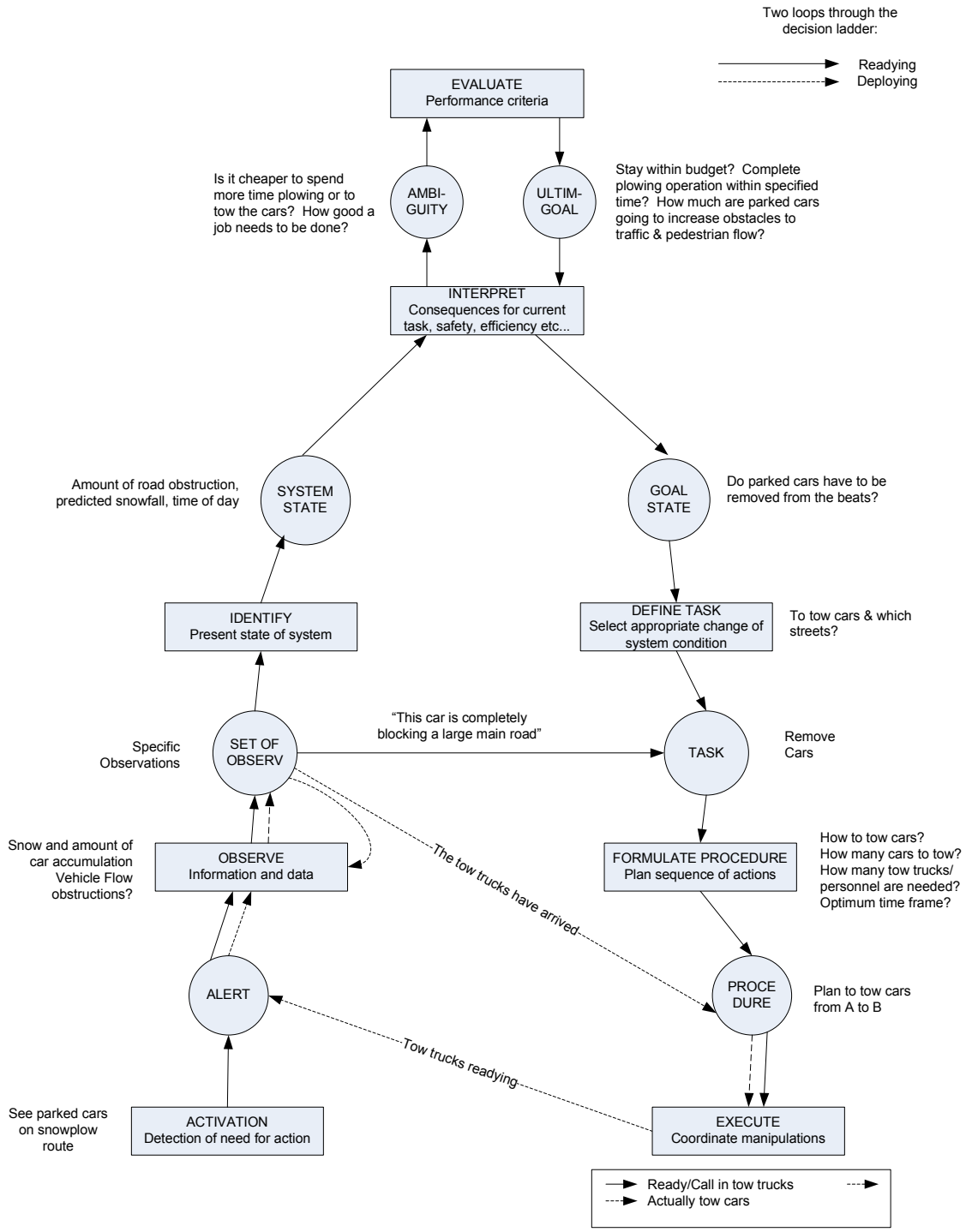

Figure 10: Decision Ladder for "Friendly Towing" control task

5. STRATEGIES ANALYSIS

The purpose of the strategies analysis phase of CWA is to describe the process of how prototypical work functions can be accomplished (Rasmussen et al., 1994). Two different approaches for strategies analysis were investigated and applied to two different prototypical work functions.

5.1 Comparing strategies based on work domain criteria

The first approach presented in Appendix D-1 involved looking at strategies as a means of combining and transitioning between control tasks or different ways of using state variables within a control task. This method included examining the advantages and disadvantages of the strategy with respect to the functional purposes identified in the Abstraction Hierarchy (see Section 2.2) and with respect to a set of performance criteria we developed. We chose to investigate salt dissolving (analogous to brine production), which is a physical process that actors reason about when performing the De-icing control task. This particular control task was chosen because the task involved balancing natural physical laws, considering legal constraints, and equipment variability. The strategies identified for dissolving salt in the context of the MWMP are:

- Spread rock salt directly on road
- Spread rock salt pre-wetted with water
- Spread rock salt pre-wetted with brine
- Apply brine directly on road

These strategies were compared against each functional purpose tradeoff and performance factor. We generalized that the different strategies may vary in workload (planner and equipment operator) and in the time to perform the control task (in-house[9] time and field time[10]). A rating scale using the symbols +, -, and = was used as a means of comparing the strategies across each dimension. The '+' meant that the strategy was positive with respect to dimension, '-' meant that the strategy was negative, and '=' meant that the strategy was neither positive nor negative on a dimension. In addition to these symbols, where necessary, the cells were annotated with the rationale as to why a particular rating was assigned.

The results of the analysis show that the strategy of 'Spreading rock directly on road' generates the most positive ratings in terms of the performance factors but conversely generates the most negative ratings with respect to the functional purpose tradeoffs. The strategy of 'Spreading rock salt pre-wetted with water' had very little impact on performance factors and relatively no impact on the functional purpose tradeoffs. Spreading rock salt pre-wetted with brine was rated negatively because of the additional activities associated with brine production and yet had very little impact on the functional

[9] In this context, 'in-house' refers to activities performed by employees of the MWMP, including transportation.

[10] Field time encompasses the time from which the salt or brine is deposited on the roadway to the time where natural processes of dissolving and melting have resulted in the desired system state change.

purpose tradeoffs. Finally, the strategy of 'Spreading brine directly on road' generated a positive rating with respect to field time and overall positive ratings for the functional purpose tradeoffs because of the minimized amount of salt usage.

These strategies offer more support for decision-makers than a normative strategy formulation (Vicente, 1999) in that they do not specify a sequence of operations, but instead indicate options for which means to accomplish a change in system state can be employed. They capture work domain constraints and provide support for choice of decision-making based on the functional purpose requirements of the system at any point in time.

5.2 Comparing strategies based on decision-making criteria

In our second analysis we compared the definition of a strategy as a "category of cognitive task procedures that transforms an initial state of knowledge into a final state of knowledge" (Vicente, 1999). We used this definition to better incorporate "mental" strategies associated with the information processing steps of a control task. As documented in Appendix C-2, we looked at the various mental strategies that may be used to complete selected data processing activities of a decision ladder tree for De-icing. These mental strategies are summarized below.

Table 5: Strategies Identified for Reviewed Data Processing Activities for the De-icing Task

Data Processing Activity	Strategy
Activation	Self-activated
	External activation (field sensor - i.e.patroller)
	External activation (field sensor - i.e.call centre)
Observe Info / Data	Observe all state information (exhaustive)
	Observe the information as it comes in and assume the rest (serial and self-terminating search)
	Observe with past experience or protocol and sample selected info and assume the rest (structured search)
Identify System State	Generalize from limited observations using stored mental model (use of heuristics)
	Use related observations to deduce unknown system state variable (e.g. snowfall rate and pavement temperature = guesstimate of snow accumulation)
Formulate Procedure	Select a pre-planned set of beats
	Select custom subset of pre-planned beats
	Generate beats with pre-planned procedure templates
	Generate freeform custom routes

To provide a basis for differentiating these information processing strategies, it was necessary to develop performance criteria that were specific to the activities[11]. In addition, each mental strategy was analyzed with respect to the functional purpose tradeoffs to see what impact the strategy may have on the work domain. To improve the resolution of performance measurement, the rating system was changed to a five point numbering system from 1 to 5 where 1 was regarded as the most negative score and 5 was considered the most positive score. The selection of which strategies to use are not simply determined by the "highest scoring" strategy – however a strategy that rates well across all categories would be expected to be employed frequently. However, the relative importance of each category will change depending on context.

The analysis yielded several interesting observations. For the "Formulate Procedure" information processing activity, the possible strategies we identified have a marked difference in their demands on the decision maker and their likely effect on functional purposes. We discuss each of the strategies in turn:

Select a pre-planned set of beats:

This strategy has the lowest demand on all cognitive resources as little to no consideration of the work domain is performed. Pre-planned routes can be designed to meet legal, transportation impact and safety requirements, at the expense of budget and environmental impact due to salt over-use. However, this strategy cannot be used if the number of drivers and trucks required exceeds that available.

Select custom subset of pre-planned beats:

This strategy requires the planner to choose a sub-set of pre-planned beats to deploy. This requires more knowledge of the appropriate change in system state, and therefore more knowledge of system and goal states. Overall, the salt use will be more effective, though the structure of pre-planned beats may still lead to over- or under-salting on a street-by street basis.

Generate beats with pre-planned procedure templates:

This strategy requires cognitive resources and knowledge of the work domain to generate custom routes and salt spreading rates based on procedure templates[12]. The output state of knowledge is more complex than a pre-planned beat, which will require increased actor competency in interpreting. The increased dependence on these cognitive factors introduces risk into the functional purpose tradeoffs. If successful, this strategy can perform well on almost all functional purposes.

Generate freeform custom routes:

This strategy consists of a completely dynamic generation of route and salt spreading rate 'on the fly'. It requires extensive and detailed work domain knowledge and complex cognitive activity to integrate system information and update procedures continuously. If successful, this strategy has the potential to optimize salt application to every location in

[11] We have not justified our choices in the development of the performance criteria relevant for each data processing activity. The performance criteria were developed based from a combination of examples from the referenced material and assumptions of the cognitive issues associated with an activity.

[12] These templates are currently used by planners to determine the size of truck required based on the beat length, application rate and number of lanes.

the city. If done poorly, confusion and disorganization could result in catastrophically poorer performance.

It should be noted that these strategies are not exclusive and that actors can select between these strategies dynamically in response to system conditions. For example, an actor could select a subset of pre-planned beats to deploy. In the process of selecting pre-planned beats, knowledge of a constraint in the work domain, for example a blocked route due to road construction, could result in a need to switch to generating a custom beat for a vehicle. Another actor executing the pre-planned beat could switch to a custom freeform strategy in response to another disturbance, for example navigating around a vehicle collision, and resume the pre-planned beat afterwards.

6. SOCIAL ORGANIZATION AND COOPERATION ANALYSIS

The fourth phase of CWA can be divided into two sub-phases: Content and Form. Content determines how the work should be divided and Form determines the organizational structure and how the actors communicate with each other. We investigate each in turn.

6.1 Content: Division and Coordination of Work

6.1.1 Identifying prototypical actor roles

In the first step of the social organisation analysis we examined how the work could be divided between actors. We defined prototypical actor roles in order to differentiate between classes of actors and the work they are expected to achieve. The following prototypical actor roles were defined for the analysis based on existing practice:

- Drivers, Labourers and Heavy Equipment Operators
- Inspectors
- Yard Supervisors
- Inspection Supervisors
- Managers
- Weather forecasters

In the course of this analysis we will not restrain our consideration of prototypical actor roles to current practice. In keeping with the formative approach of CWA we will attempt to identify ways in which work could be divided.

6.1.2 Worker Reasoning Space

To show the reasoning space of workers, we generated an abstraction hierarchy divided between object worlds (Figure 11). This uses the horizontal dimension to divide between object worlds as used for Burns & Vicente's engineering design case study (Vicente, 1999). The winter maintenance work domain is large and multi-faceted and so workers will not reason in the entire space but instead use different areas of the work domain at different levels of detail.

A limitation of this representation is that it represents the work domain at a single level of decomposition, in this case the Sub-System level. When workers in the system are reasoning at higher levels of abstraction, they tend to reason at a higher level of aggregation. For intermediate levels of abstraction such as Generalized Function, we could expect that workers would reason at many different levels of decomposition. For example, managers will be interested in knowing if traffic flow is congested, while inspectors will be concerned with vehicle flows on specific streets and predictions for future trends. Likewise, Physical Form and Physical Function levels of aggregation will tend to be considered at finer levels of decomposition.

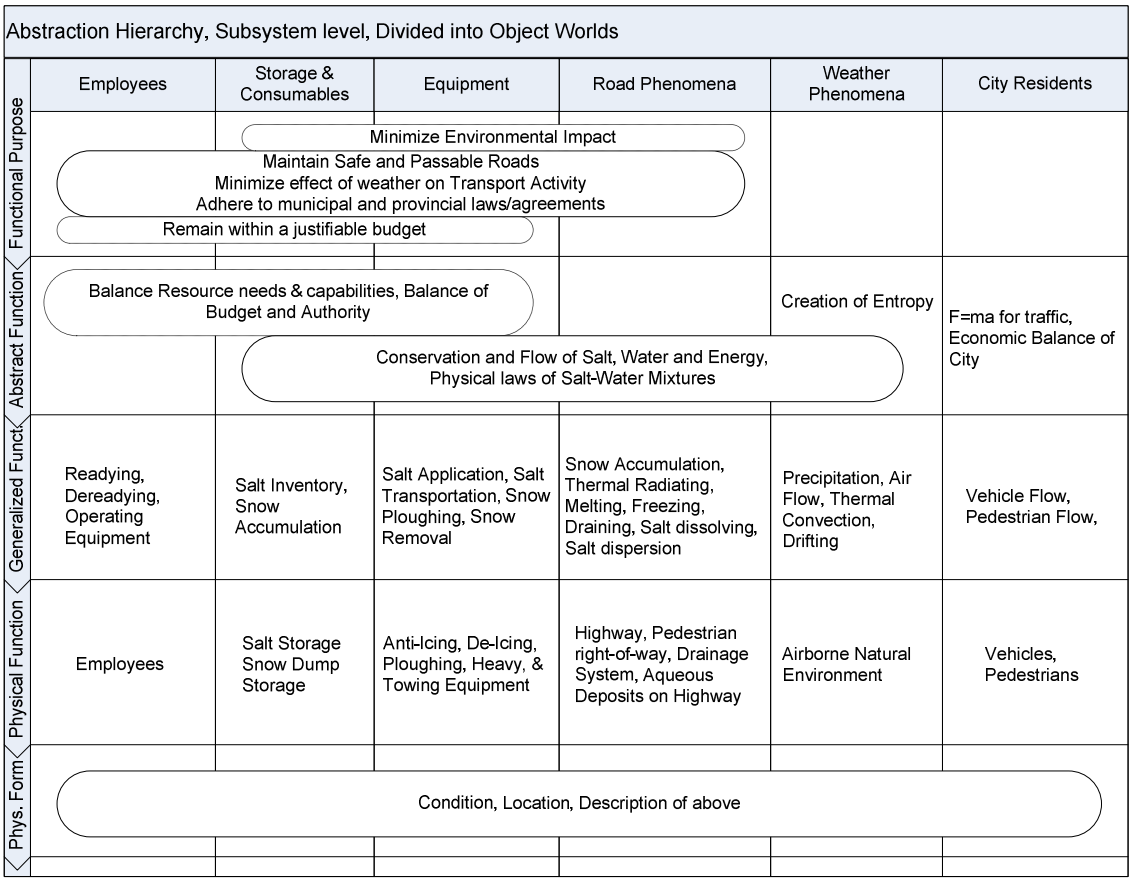

Figure 11: The abstraction hierarchy divided between object worlds

With the workers reasoning space defined, we can describe the prototypical worker roles in more detail. We used the criteria identified for dividing worker roles (Vicente 1999, Rasmussen 1994) and have highlighted their appearance in the following description.

6.1.3 Defining prototypical Worker Roles

For the drivers, labourers and heavy equipment operators, the division of work is based on union regulations and *actor competency*. These are human workers that are trained in the skills required for use of particular equipment (e.g. plough) and the rules to achieve a generalized function (e.g. snow ploughing). These actors primarily reason within the lower levels of the Equipment object world. They communicate with each other and to their Yard Supervisor.

The division of work demands to Inspectors depends primarily on *access to information*. These actor(s) are responsible for monitoring the road & traffic conditions and deciding when to initiate de-icing activity since they have the most immediate access to these conditions. This role could be either allocated to human workers or an automated sensor network, for example.

The allocation of work to the Yard Supervisors is based on *actor competency* and *communication*. They are responsible for the coordination and deployment of workers at their yard/camp. These workers tend to reason inside the Employees, Storage & Consumables and Equipment object worlds.

The allocation of work to the Inspection Supervisors is based on *actor competency* and *communication*. They are responsible for coordinating the inspectors and for deciding when to initiate anti-icing, de-icing and ploughing operations. These workers tend to reason inside the Road Phenomena, Weather Phenomena and City Residents object worlds.

The Managers are allocated the task of overseeing operations and ensuring the winter management system meets the functional purposes. This allocation is based primarily on *actor competency*. Managers reason at higher levels of abstraction over all object worlds and depend on communication with other prototypical worker roles to effectively perform their roles.

The allocation of weather forecasters to weather phenomenon is based on *competency* and *access to information (functional decoupling)*. These human and automation actors will focus on understanding the current state of the weather and predicting future states.

6.1.4 Mapping actors onto the abstraction hierarchy

Since the tasks and demands during each prototypical work situation differ, the prototypical worker roles were mapped onto the abstraction-'object world' space for each prototypical work situation identified in the Activity Analysis. This representation was adapted from previous work in which the roles of anaesthesiologist and surgeon during a surgery control task were mapped onto an Abstraction-Decomposition space (Hajdukiewicz et al., 1998).

The mapping of worker roles in the "Ploughing" Control Task is given as an example below, and representations for the remainder of the work situations are included in Appendix D

6.1.5 Ploughing

As shown below in Figure 12, the entire work domain is under consideration during ploughing operations.

Drivers and Heavy Equipment Operators are concerned primarily with the operation of their vehicles to achieve a certain generalized function. This requires reasoning in Equipment and Road phenomena object worlds at low levels of abstraction. For example, they would be concerned with the location and shape of roadway obstacles (Physical Form), the capability of their equipment to plough snow (Physical Form), and the snowploughing process which they have been assigned to perform (Generalized Function).

Inspectors reason at the same levels of abstraction as drivers about a wider variety of object worlds. They must observe elements of the work domain including equipment performance, traffic flows, weather phenomena, and road phenomena. Because of the large quantity of data gathered, this information must be aggregated for decision making use.

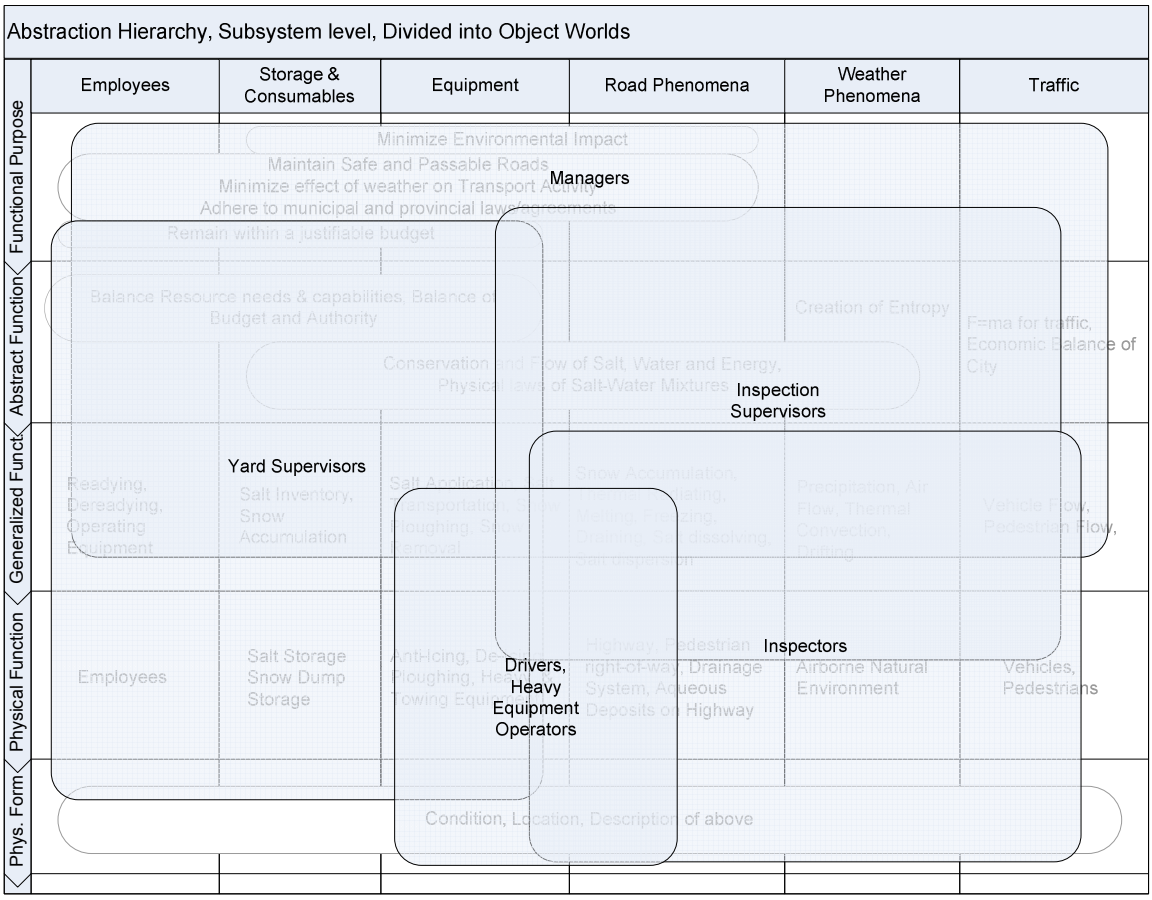

Figure 12: Mapping of actors on the AH during Ploughing

Inspection Supervisors use this aggregated data to reason at higher levels of abstraction to identify the state of the road network and weather phenomena. They advise and discuss with Managers aspects of functional purpose decision making.

Yard Supervisors are responsible for reasoning about the system state of the employee, storage, and equipment object worlds, primarily in MWMP Camps and Equipment Yards. The physical size of this portion of the work domain is smaller, and allows for one worker to more directly observe and interpret the state of the system. They provide a link between managers and individual Drivers by communicating procedures and relaying observations. They interpret these observations and perform advising and discussing with Managers.

Managers are responsible for ensuring functional purpose goals are being achieved, since the ploughing prototypical work function has an associated increased potential impact on city economic activity and on budgetary expenditures. They would typically reason between the Generalized Function and Functional Purpose levels of abstraction and would consider the entire work domain at an aggregated level of detail as discussed above.

6.2 Form: Social Organisation

6.2.1 Identifying Communication Requirements

The prototypical worker roles introduced above were adapted from the current organisational structure of the MWMP, which contains many more roles than those actually modeled. The current work organisation and communication network was analyzed by means of a communication matrix (Rasmussen et al., 1994) included in Appendix D-1. Entries in the matrix link an information source to an information receiver. Rather than simply identifying a connection, this representation was adapted to include the means of communication (e.g. direct conversation, cell phone, two-way radio, paper form, website, etc) as indicated in the "Communications Guidelines for Storm Response" (Transportation Services, 2005).

One observation that has implications for systems design is that the existing communication system transmits information via many different sources to actors in the system. The current two-way radio communication used by drivers and inspectors facilitates transfer of knowledge of observations between actors. The vocal/aural mode is appropriate as it should interfere less with the visual/motor activity of operating heavy equipment. Another means of communication used between low-level workers and their supervisors are an assortment of daily paper logs and forms, which serve a documentation purpose but are burdensome and potentially a source of data conversion inaccuracy and inaccessible information. The design evaluation of an appropriate social communication system could be considered for future research.

6.2.2 Mapping actors on to a social organisation

Since the MWMP covers such a large, diverse geographic area, it has been divided into four districts (north, south, east and west). This could potentially be an area where CWA could be used to redefine the boundaries and/or number of districts. Districts have similar, but also distinct capabilities and constraints. For example, the downtown core (currently South District) has many narrow, one-way streets and very little snow storage. On the other hand, it has higher average temperatures and receives less snow than the suburb areas north of highway 401 (currently North District) and so most storms can be treated with de-icing operations as opposed to ploughing operations.

CWA could suggest that the district organizational boundaries be drawn to contain more homogenized constraints relating to weather phenomena, environmental impact and road networks, as well as social constraints (e.g. communication). This could facilitate decision-making by simplifying the operation of interpreting observations into knowledge of system states. District sizes could be constrained by limitations to acceptable mobilization delays and effective operational range of vehicles.

A proposed social organisation is shown in Figure 13. Each district has yards to store equipment and camps to store equipment and personnel. These are distributed geographically so as to minimise travel time on the road network. An authority related hierarchy (adaptive model) is mirrored across each district and communication between districts starts at the Supervisor level.

During routine operations between storms, most of the communication is between low-level actors and their supervisors. Yard workers are involved in maintenance activities and managers are involving in planning activities. Inspectors are a source to trigger winter maintenance activities and are given the authority to call a first round of de-icing.

During storms with more significant ploughing activities (such as a Type 2 storm described in Figure 6), a coordination centre is established and consists of supervisors, managers and weather forecasters. The aim is to aid decision making (knowledge-based behaviour) and to "facilitate the communication needed for coordination" (Vicente, 1999) During storm response, the authority hierarchy remains but moves towards a military type model where specific goals are communicated down to lower levels instead of overall objectives. The costs and risks are high and so the budgetary, safety and environmental responsibilities are assigned up the chain of command. Decisions for winter maintenance activities do not need to be made in very short time periods and so this hierarchy can support this type of decision making.

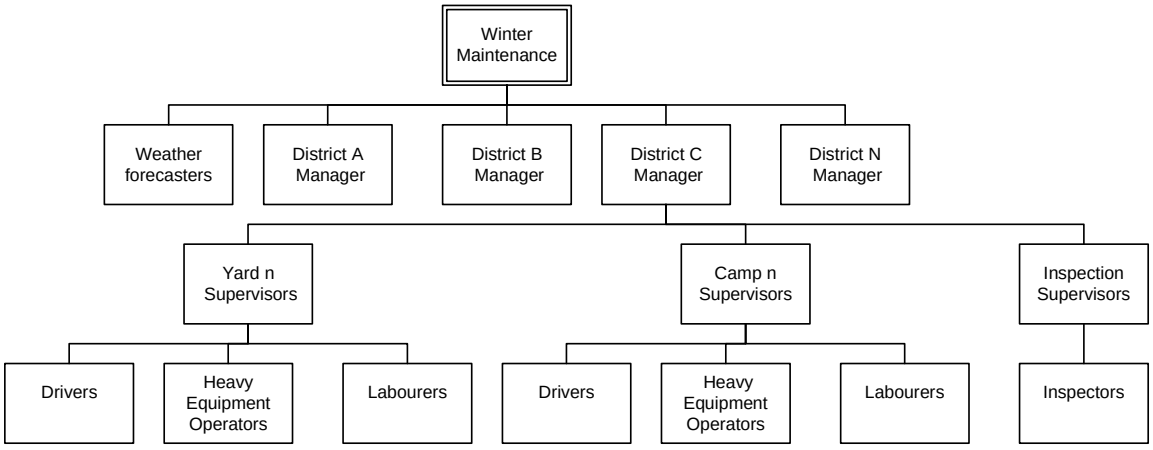

Figure 13: Formative structure of a possible social organization

7. WORKER COMPETENCIES ANALYSIS

The final stage of CWA is intended to specify what cognitive abilities that actors must possess to successfully perform their assigned work functions in the System. The results of previous phases of analysis provide a foundation in which the required worker competencies of a set of actors under consideration can be evaluated. We employ the Skills, Rules, Knowledge (SRK) taxonomy as developed by Rasmussen (Rasmussen, 1983) to classify and provide a framework for this analysis of performance.

7.1 Signals, signs and symbols in the MWMP

The "Friendly Towing" Control Task can be used to illustrate examples of how observations of elements of the work domain can be interpreted as signals, signs or symbols and support skill-, rule-, or knowledge-based behavior for a variety of actors.

A parked car on a busy snow-filled road could be interpreted as a signal by a snowplow driver, prompting her to maneuver the snowplow around the vehicle using subconsciously-coordinated sensorimotor movements. An Inspection Supervisor, on being notified by an Inspector or Driver of the parked car now being surrounded by snow from the snowploughing activity, could interpret the parked car as a symbol implying that cleanup ploughing operations or friendly towing activities might be required to maintain functional purpose goals of minimizing impact on city economic activity and safe and passable roads. The Tow Truck Driver assigned with the task of clearing parked cars from a specified area of the road network would interpret the parked car as a sign that he would recognize as a cue for the task of towing the car.

7.2 SRK-based behaviour for alternative strategies

In Section 5.2, we discussed potential strategies that could be used for the “Formulate Procedure” information processing activity in the De-Icing control task. The different options for matching resources to demand had different demands on actor cognitive abilities and had different potentials for satisfying functional purposes.

The greatest potential for performance was also associated with the highest demands on decision-making abilities. Using a fixed distribution of responsibilities between actors, we can model the required worker competencies for three prototypical worker classes: Planners, Yard Supervisors, and Drivers.

The results are presented in Table 6 for the “Select Custom subset of pre-planned beats” strategy and Table 7 for the “Generate Custom Freeform Routes” strategies identified in Section 5.2.

Table 6: De-Icing with the strategy "select custom subset of pre-planned beats"

	Planner	Yard Supervisor	Driver
Skill-based behaviour (signals)	None	None	Info from the driving scene is interpreted as signals for sensori-motor control of the vehicle
Rule-based behaviour (signs)	Use of previous experience and problem-solving to generate rule-based procedures	Knowledge of a set of observations or of the system state (snow accumulating) cues an associated task (De-Icing) and associated activity timing and routes	Search for cues in the environment to follow prescribed route. Road signs, communication codes.
Knowledge-based behaviour (symbols)	Examine hypothetical system states and interpret consequences for possible goal states (reason analytically)	Knowledge of a set of observations informs heuristic thought experiments concerning decisions (redeploy salters?)	Varies: troubleshoot equipment malfunctions, navigational workarounds

Table 7: De-Icing with the strategy "Generate freeform custom routes"

	Planner	Yard Supervisor	Driver
SBB (signals)	None	None	As above
Rule-based behaviour (signs)	None	Knowledge of a set of observations or of the system state (snow accumulating) cues an associated task, with no pre-defined timing or routes	Search for cues in environment to dynamically generate route. Match salt application rate to snow accumulation on roadway, etc.
Knowledge-based behaviour (symbols)	Examine hypothetical worst-case of system states and check that ends can be satisfied by available means	Determine required change in system conditions (Task), based on desired goal state	As above, plus maintain dynamic mental model of road network conditions & history. Coordinate future actions with other actors.

The custom freeform routes strategy requires many knowledge and rule-based competencies from Drivers. They must not only skillfully operate their vehicles to avoid obstacles, but also engage in an additional problem-solving activities to determine where to drive and how much salt to apply. It is clear why this strategy is not currently employed by the MWMP since most plough drivers are contractors who cannot be expected to reason analytically about snow-salt mixtures and system functional purposes.

If this strategy is to succeed, the driver will require some form of support in rule and knowledge based behavior. A navigation aid in the form of a co-driver or computer-based system could reduce workload at both levels. Training could help in associating states with tasks and providing heuristics for knowledge-based reasoning.

8. CONCLUSION

The preceding six sections have outlined our approach to a CWA of the MWMP. We conclude this document with a discussion of difficulties encountered and possible applications.

8.1 Challenges to Incorporating the Formative Approach

CWA is classified as a formative approach to work analysis, as compared to normative or descriptive methods (Vicente, 1999). We met with varying levels of difficulty in maintaining the principles of formative approaches during this analysis, which we will describe in further detail here.

The research team's access to workers in the domain was extremely limited. Interviews with Peter Noehammer, P.Eng, provided some SME insight into the managerial perspective on the work system. However the expertise of yard supervisors, patrollers, and equipment operators was not solicited and no validation of the work domain analysis was performed to ensure that it accurately and completely reflected the reasoning space of workers in the system.

Likewise no direct observation of workers' control tasks was undertaken. Typically, observations of workarounds and of decision shunts and leaps by experts help expose the structure of control tasks. Data sources and controls that workers employ to interact with the work domain were also not observed.

The largest source of information used in the generation of this analysis is the written documentation furnished by the MWMP administration. This documentation is generally written from a normative point of view, with instructions concerning physical work domain constraints, such as the optimal 23% concentration to achieve the lowest salt brine mix freezing point, and prescriptive procedures for workers to follow, such as pre-planned driving routes.

This documentation prescribed criteria for selecting strategies for some activities, such as formulating procedures for accomplishing salting or ploughing tasks. Other activities such as observation of system variables were also heavily prescribed through the requirements for various forms to be filled out by system actors. Activities relating to high-level decision making tasks were more vaguely encouraged through rule based statements such as 'if a storm is incoming, perform x, y, or z'

The documentation also contained detailed specifications of organizational structures and communication protocols, which we assumed reflected current practice. For the purposes of analysis, some of the detail of this descriptive information was aggregated in the process of adapting it to a formative representation.

It has been suggested that the availability of information from managers and designers in the form of interviews and documentation is the most important type of information for the first and second phases of CWA, which is where the scope of this report is widest

(Vicente, 1999). Lack of knowledge elicitation has most definitely decreased the scope of detail possible for later stages of the analysis.

8.2 Future Directions

Several possible applications of this CWA have been discussed throughout this analysis. Possible contributions to improving the functioning of the MWMP include:

1. Informing planning and decision-making activities through recognizing work domain constraints and analysis of tradeoffs between choices of means-ends as discussed in Section 5.1
2. Designing new communication networks and mediums as discussed in Section 6.2.1
3. Redrawing organizational boundaries and defining new organizational structures in accordance with work domain and task constraints as discussed in Section 6.2.2
4. Enabling alternate strategies of operation through improved worker training or design of decision support tools as discussed in Section 7.2.

We found the modeling experience very educational. To our knowledge, a Cognitive Work Analysis of such a large, distributed system with a combination of naturally occurring phenomena, unplanned intentional and physical constraints, and engineered system components has not been previously performed. There are many areas of this analysis that could be expanded in more detail and revised for a more rigorous, consistent discussion. A further investigation with one of the identified improvements in mind may lead to a more focused results-based analysis.

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10. APPENDIX A – WORK DOMAIN ANALYSIS FIGURES

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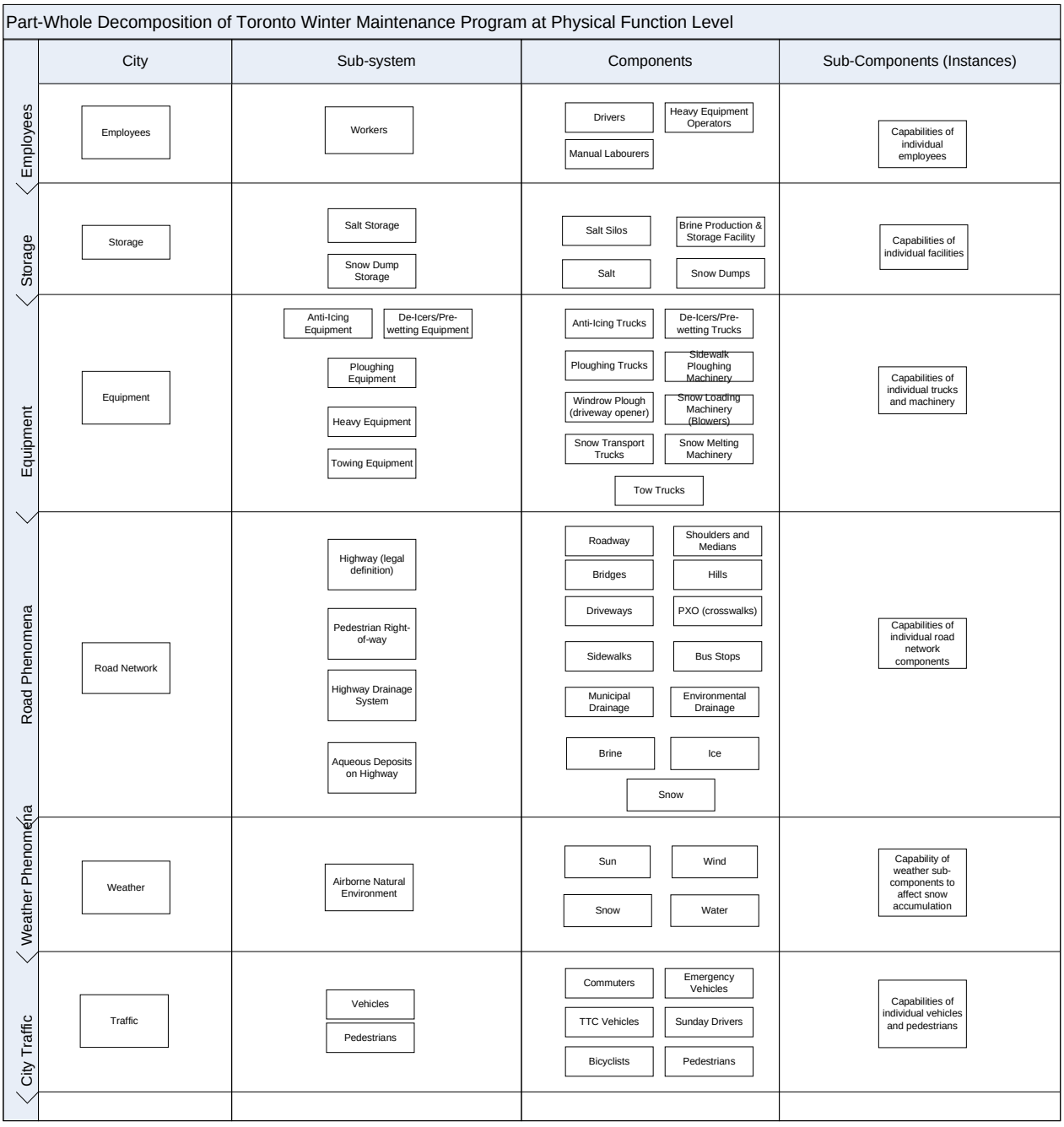
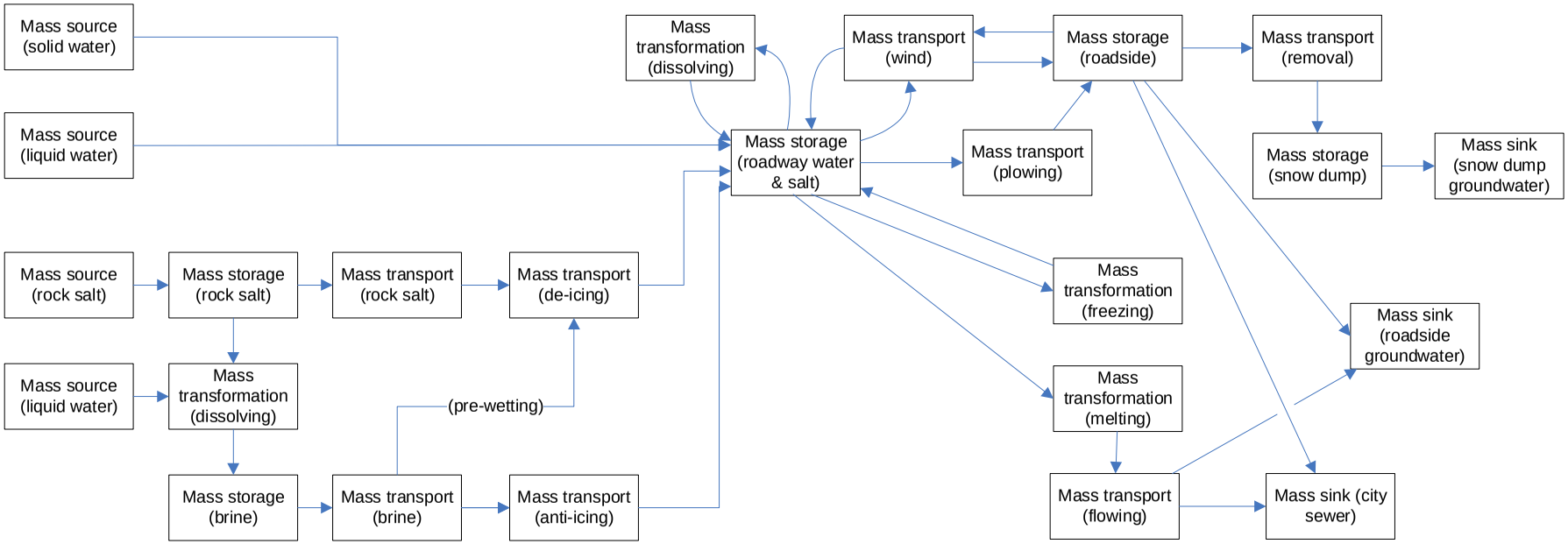
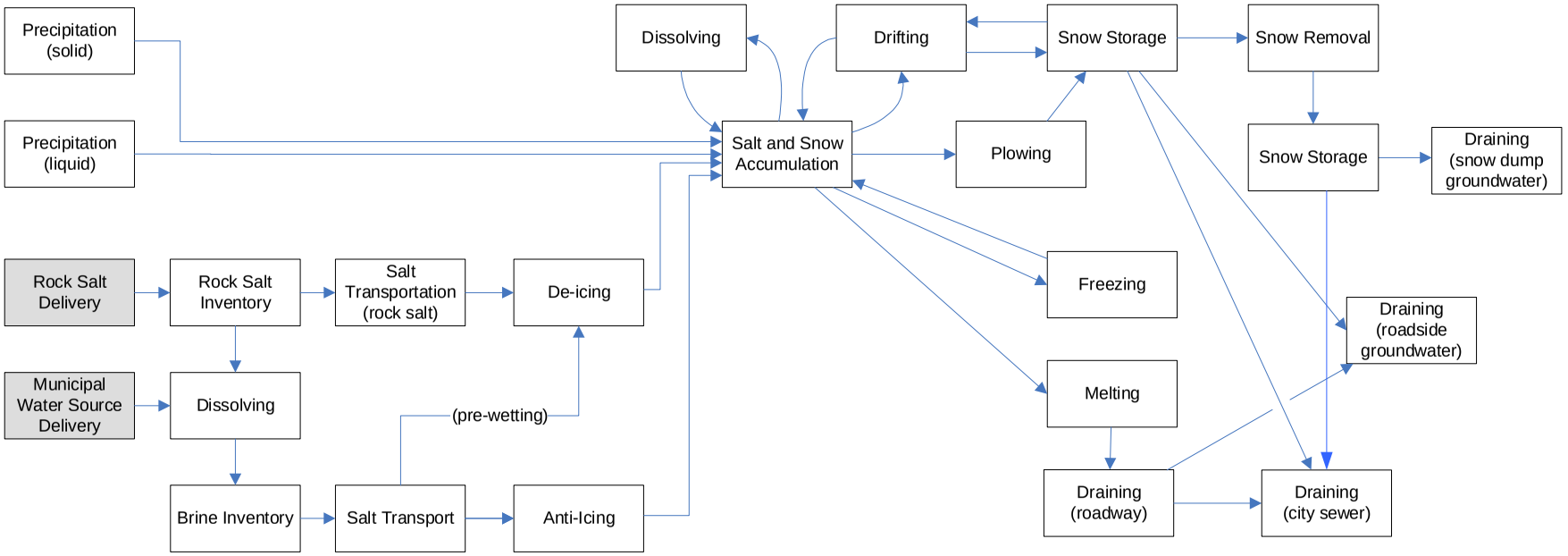


Appendix A - 2 Part-Whole Decomposition (Physical Function Level)



Appendix A - 3 Integrated Salt and Water Causal Abstraction Hierarchy Representation (Abstract Function Level)

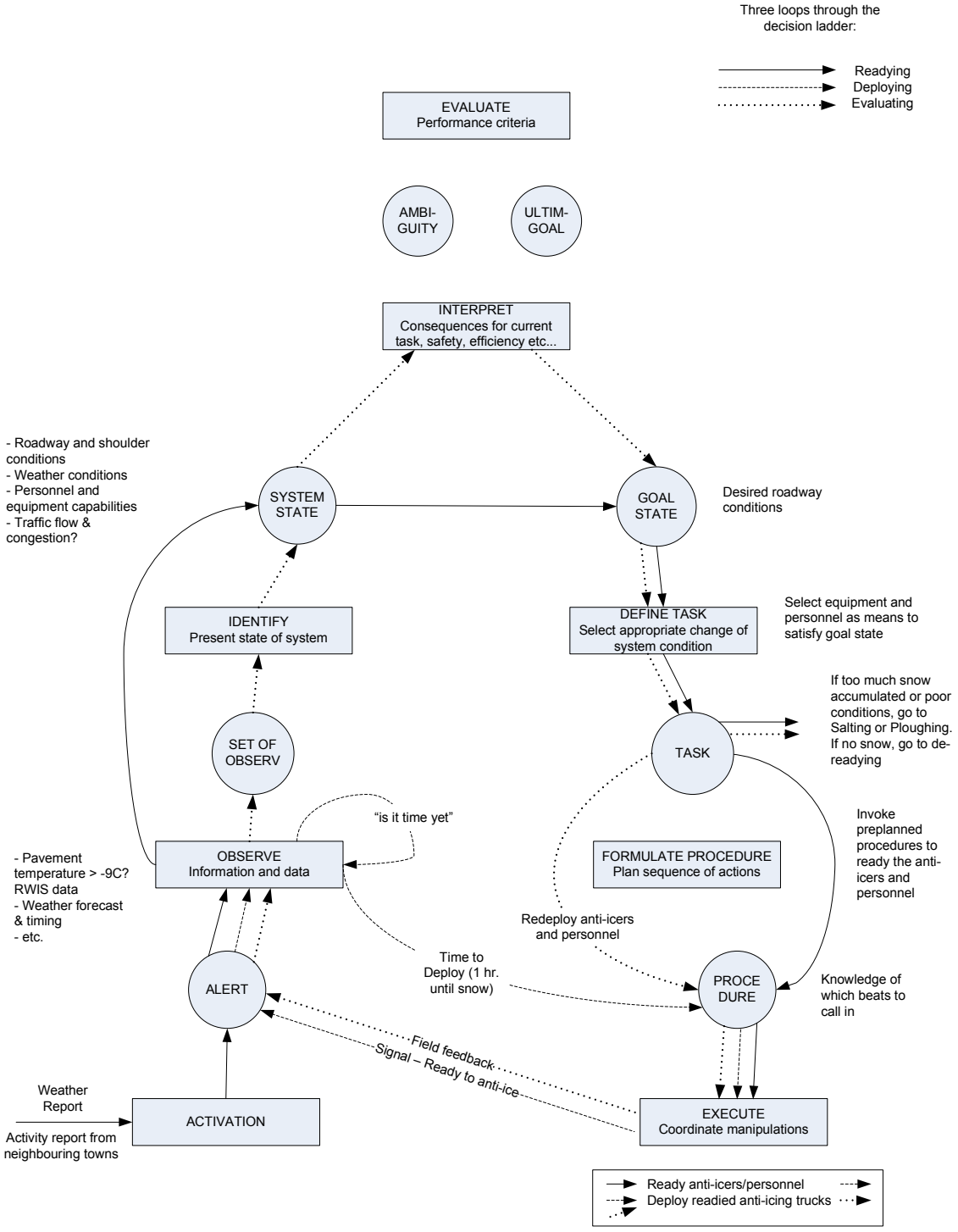


Appendix A - 4 Integrated Salt and Water Causal Abstraction Hierarchy Representation (Generalized Function Level)

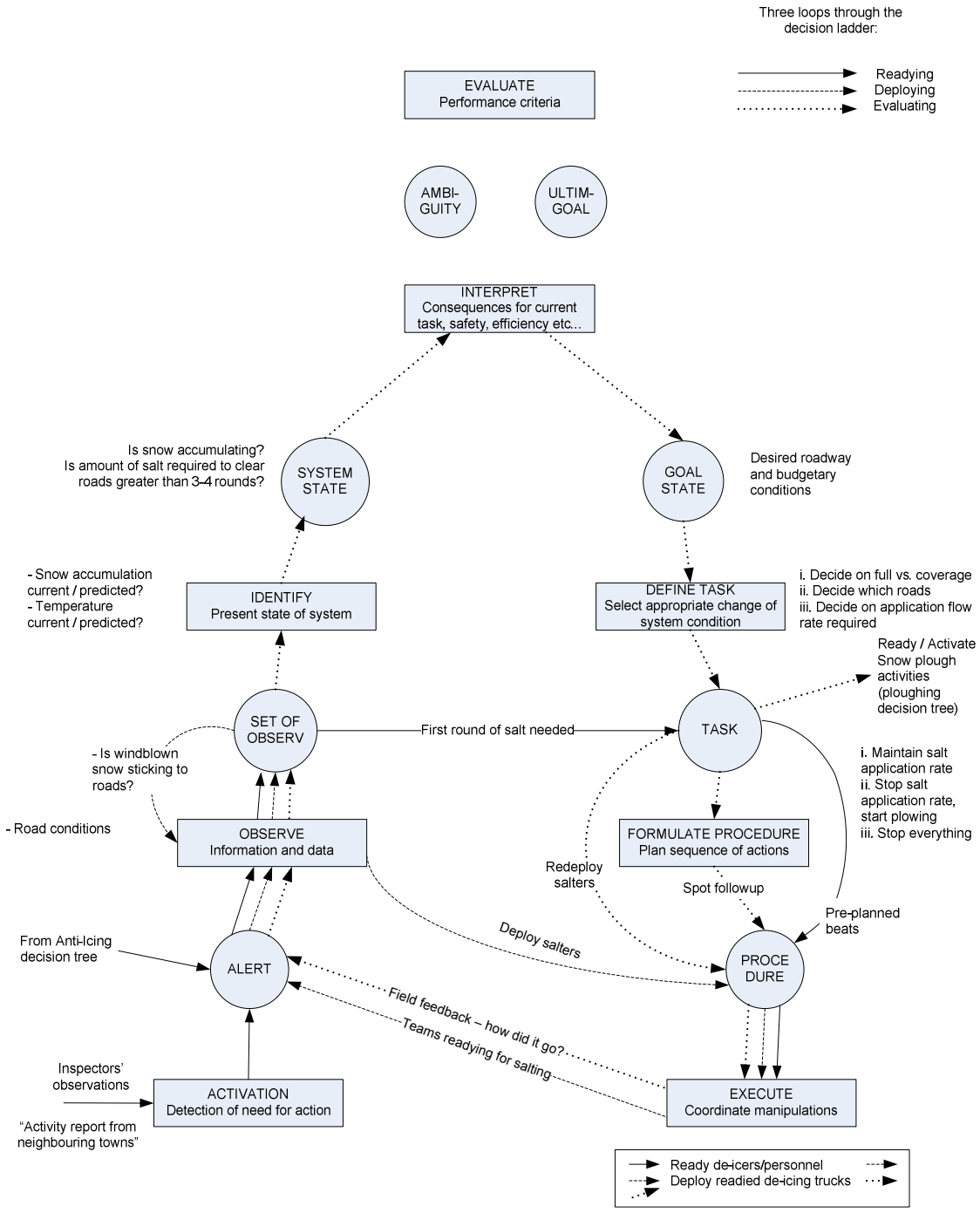
Abstraction Hierarchy Item	Variable	Have it?	Can Get It?	Calculate It?
Maintain Safe and Passable Roads				
Minimize Environmental Impact				
Remain within a justifiable budget				
Adhere to laws and agreements				
Minimize impact of weather on transport				
Conservation, balance and flow of salt				
Brine Production	Current rate of brine production at facilities and on road		x	
Salt Transportation	Current rate of salt being transported from A to B		X	
Salt Inventory	Amount of Salt in Domes at Camps / Yards	X		
Salt Sink	Current rate of salt flowing in brine into ground / drains			
Salt application	Current rate of salt being applied			
Rock Salt	Location of all forms of salt in the city (parts of other objects)		x	
Salt Silo	Capacity of salt storage	X		
Roadway	Surface temp., snow accumulation, ice acc. Salt acc., Car acc.		x	
Anti-icer Trucks	Nonfunctional/functional/ready/activated/deployed Amt. Of Salt On Board / Rate of salt dispersal		X	
De-icer Trucks	" (trucks)		X	
Ploughing Trucks	" (trucks)		X	
Windrow Plough (Driveway Opener)	" (trucks) and ?		X	
Sidewalk Ploughing Equipment	" (trucks), Rate of sidewalk ploughing		X	
Snow Loading Equipment (snowblower)	" (trucks), Rate of snow loading		X	
Snow Melting Equipment	" (trucks), Rate of snow melting		X	
Snow Transport Equipment	" (trucks), Rate of snow transporting		X	
Brine Production Facility	In use / not in use / functional / nonfunctional		X	
Brine	Inventory of Brine @ Locations	X		
Balance and flow of water forms	-			
F = ma as applied to traffic	Relative risk of skidding and collisions			
Creation of Entropy	-			
Physical laws governing salt-water mixtures	-			
Draining	Rate of water flow @ Locations			
Snow Ploughing (shifting on roads)	Rate of snow ploughing being performed		X	
Snow Removal (transport from roads)	Rate of snow removal being performed		X	
Snow Accumulation	Amount of snow accumulated @ Locations		X	
Drainage System	Current state of blockage of drains		X	
Environmental Reservoirs	Current salt concentration in water in resevoirs		X	
Snow Dumps	Functional/Non-functional, Percentage full	X		
Snow	Accumulation (reflected in other functions), rate of precipitation, temperature…		x	
Pedestrian Flow	Number of pedestrians, rate of pedestrian movement @ Locations		X	
Vehicle Flow	Number of vehicled, rate of vehicle flow @ Locations		X	
Pedestrians	-			
Vehicles	-			
Sidewalks	Snow accumulation on sidewalks,		X	
Bus Stops	Snow accumulation on Bus Stops		X	
PXO	Snow accumulation on PXO		X	
Bridges	" (roadway)		X	
Hills	" (roadway)		X	
Shoulders and Medians	Snow / Salt accumulation		x	
Air Flow	Air movement @ Locations, associated wind chill		X	
Wind	Wind velocity @ Locations	X		
Precipitation	Rate and type and duration of precipitation @ Locations	X		
Drifting	Rate of snow redistribution, accumulation/removal @ Locations			
Temperature	Temperature of air / ground @ Locations	X		
Snow/Ice Melting	Rate of melting @ Locations			x
Water Freezing	Rate of freezing @ Locations			x
Water	Phase / Form and accumulation and flow @ Locations		X	
Ice	" (Water)		X	
Balance resource needs and capabilities	(reflected in other functions)			
Deployment of Personnel	Current state of employees on work		X	
Union, city-employed workers	Capabilities of workers, cost	X		
Contract workers	" (Workers)	X		
Balance of risk and authority	Level of escalation of decision making power, rate of expenditure	X		
Economic Balance of City	Civilian business employee attendance, money flow around city		X	

Appendix A - 5 Information Availability Analysis

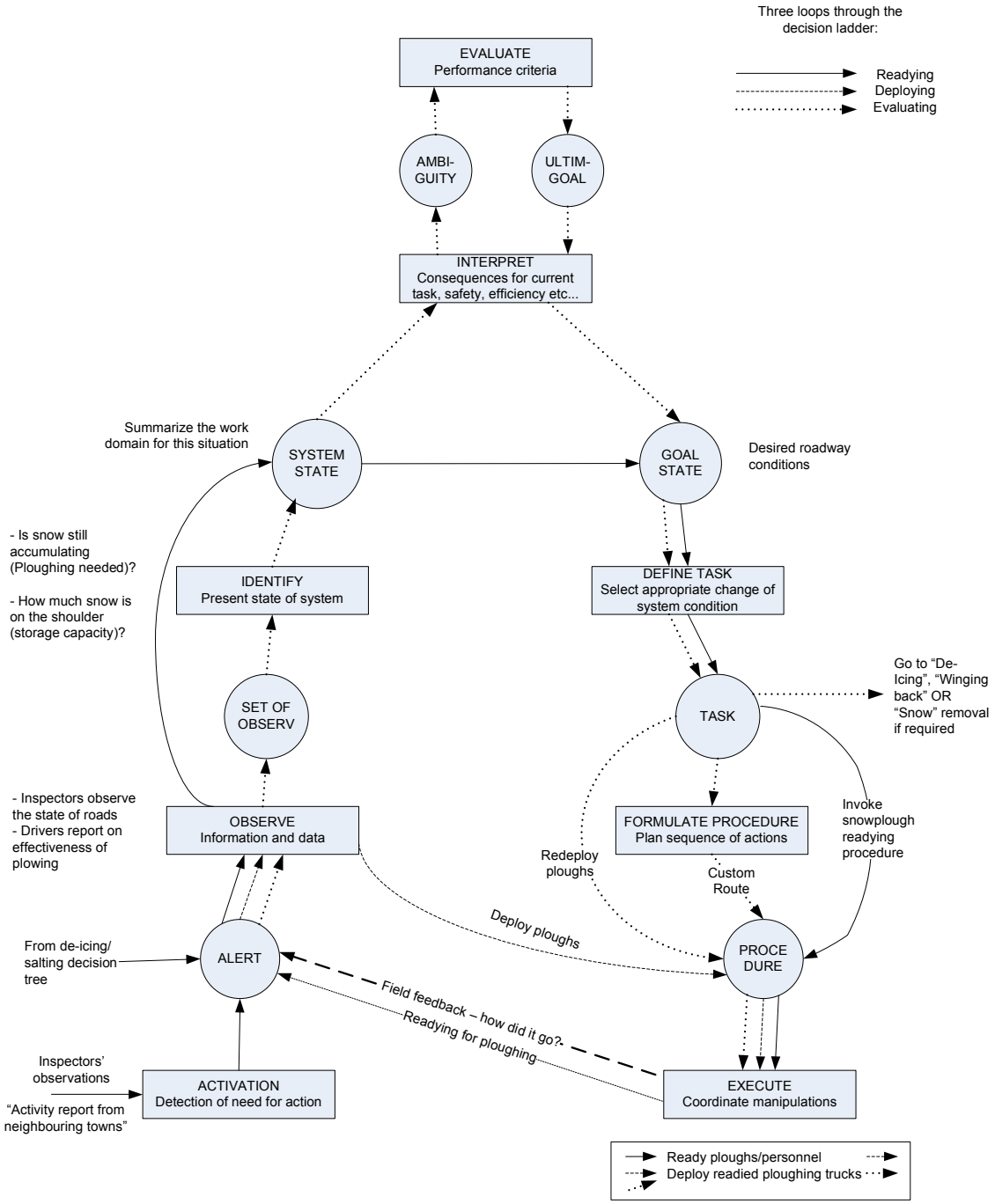
11. APPENDIX B – CONTROL TASK ANALYSIS FIGURES



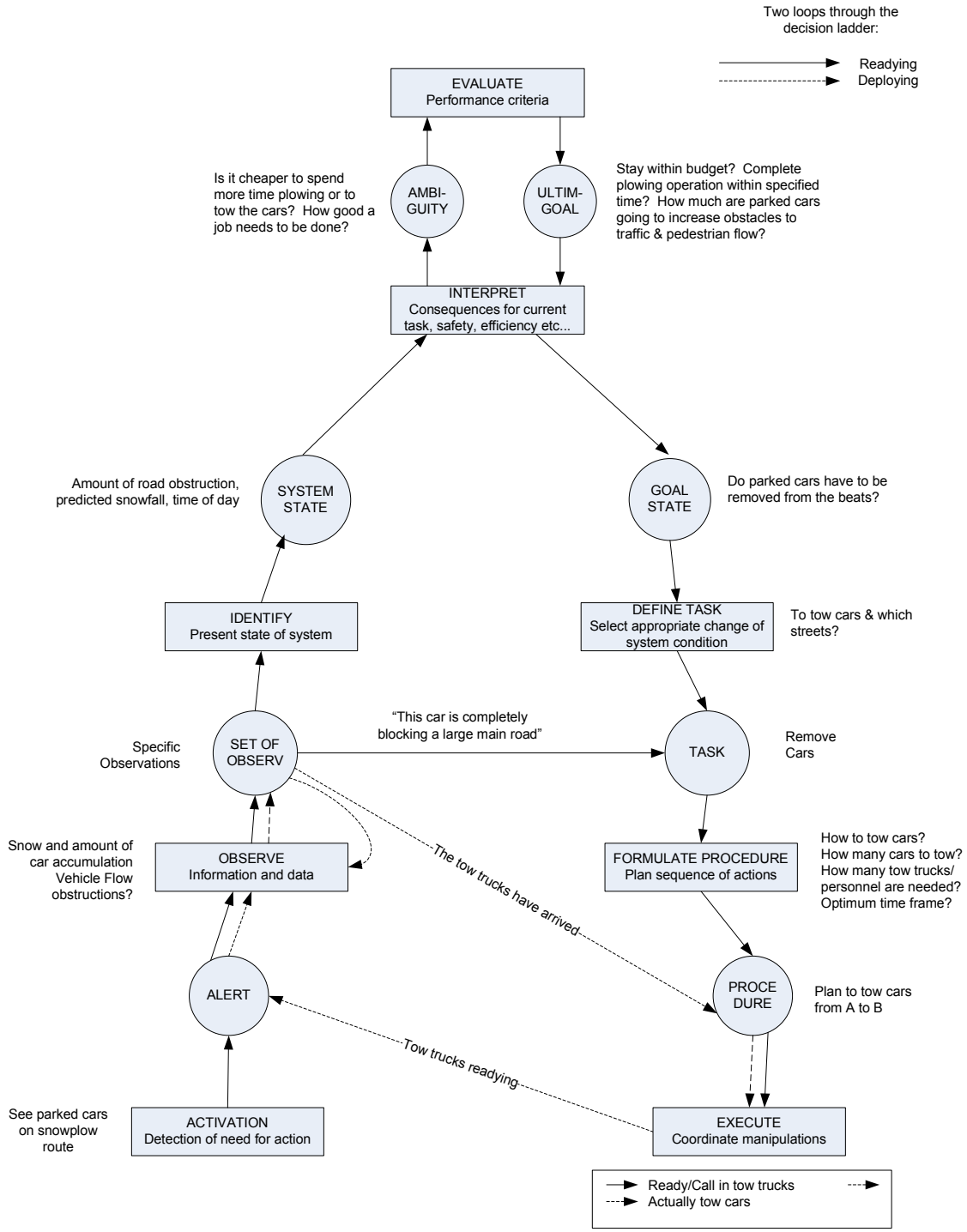
Appendix B - 1 Anti-Icing Decision Ladder



Appendix B - 2 De-Icing Decision Ladder



Appendix B - 3 Snowploughing Decision Ladder



Appendix B - 4 Friendly Towing Decision Ladder

12. APPENDIX C – STRATEGIES ANALYSIS TABLES

Strategy	Performance Factors				Functional Purpose Tradeoffs				
	Planner Workload	**Operator Workload**	**In-house time**	**Field time**	**Environment**	**Safety**	**Budget**	**City Transport**	**Legal**
Spread rock salt directly on road	+ Simple, well established loading	+ Simple equipment to operate	+ Only one easily stored chemical to load	- Natural dissolving rate is slow, heat, moisture, vehicle flow required	- Salt bounces onto shoulder	- Rock salt takes time to work, raw rock salt prevents traction	+ Salt is cheap, equipment is simple to operate/maintain	-	- Environment damage
Spread pre-wetted rock salt with water	+ Not so different from salt application	= Additional equipment to operate	- Two separate materials to load	= Accelerates natural dissolving rate	= Greatly reduced salt bouncing	= Salt can be distributed quickly, activates	= Requires some additional equipment, distributes salt quickly	= Less time required	=
Spread pre-wetted rock salt with brine	- Need to plan availability of brine as well as salt	- Even more equipment required to operate	- Two separate materials to load / prepare	+ Some pre-dissolving already achieved	=	=	- Requires brine generation facilities	=	=

Strategy	Performance Factors				Functional Purpose Tradeoffs				
	Planner Workload	**Operator Workload**	**In-house time**	**Field time**	**Environment**	**Safety**	**Budget**	**City Transport**	**Legal**
Apply brine directly on road	- Brine production facilities to be managed, timing and temperature constraints	=	= One material to load + prepare	- Can be applied before snowfall, instant activation	+ Limited to no salt escape from pavement, less salt used	+ Applied before snow, prevents ice-road bond	= Can reduce plowing expenses by breaking ice-road bond, extra brine generation costs, less salt used	+ Does not hinder grip on bare roads, works without traffic mixing	+ Low environmental impact, aids plowing rate

Appendix C - 1 Salt Dissolving Strategy Analysis using the First Approach

Strategy	Cannot Be Used If…	Performance Factors					Functional Purpose Tradeoffs				
		Time Spent	Complexity Of Cognitive Processes	Dependency On Knowledge Of Work Domain	Likelihood Of Introducing Errors	Number Of Activation Sources	Environment	Safety	Budget	City Transport	Legal
Self-activated	…actor is distracted	4	N/A	4	4	2	N/A	N/A	4	4	N/A
External activation (field sensor - i.e.patroller)	...external activation source is not available	2	N/A	3	3	3	N/A	N/A	1	1	N/A
External activation (field sensor - i.e.call centre)	...external activation source is not available	3	N/A	2	1	4	N/A	N/A	3	3	N/A

Appendix C - 2 Strategy Analysis using the Second Approach for 'Activation' Activity in De-Icing Task

Strategy	Cannot Be Used If…	Performance Factors					Functional Purpose Tradeoffs				
		Time Spent	Complexity Of Cognitive Processes	Complexity Of Output State Of Knowledge	Likelihood Of Introducing Errors	Number Of Observations	Environment	Safety	Budget	City Transport	Legal
Observe all state information (exhaustive)	…not all information is available	1	4	1	5	1	N/A	N/A	1	N/A	4
Observe the information as it comes in and assume the rest (serial and self-terminating search)	N/A	3	3	3	2	3	N/A	N/A	3	N/A	3
Observe with past experience or protocol, sample selected info and assume the rest (structured search)	…no past experience or protocol is available.	4	2	3	3	4	N/A	N/A	4	N/A	1

Appendix C - 3 Strategy Analysis using the Second Approach for 'Observe' Activity in De-Icing Task

Strategy	Cannot be used if…	Performance Factors						Functional Purpose Tradeoffs				
		Time Spent	Short-Term Memory Load	Dependency On Knowledge Of Relationships Between Variables	Complexity Of Output State Of Knowledge	Long-Term Memory Load	Likelihood Of Introducing Errors	Environment	Safety	Budget	City Transport	Legal
Generalize from limited observations using stored mental model (use of heuristics)	N/A	3	3	4	4	3	2	N/A	N/A	3	3	1
Use related observations to deduce unknown system state variable (e.g. snowfall rate and pavement temperature = estimate of snow accumulation)	…related observations are not available.	1	2	2	2	1	4	N/A	N/A	1	1	4

Appendix C - 4 Strategy Analysis using the Second Approach for 'Identify System State' Activity in De-Icing Task

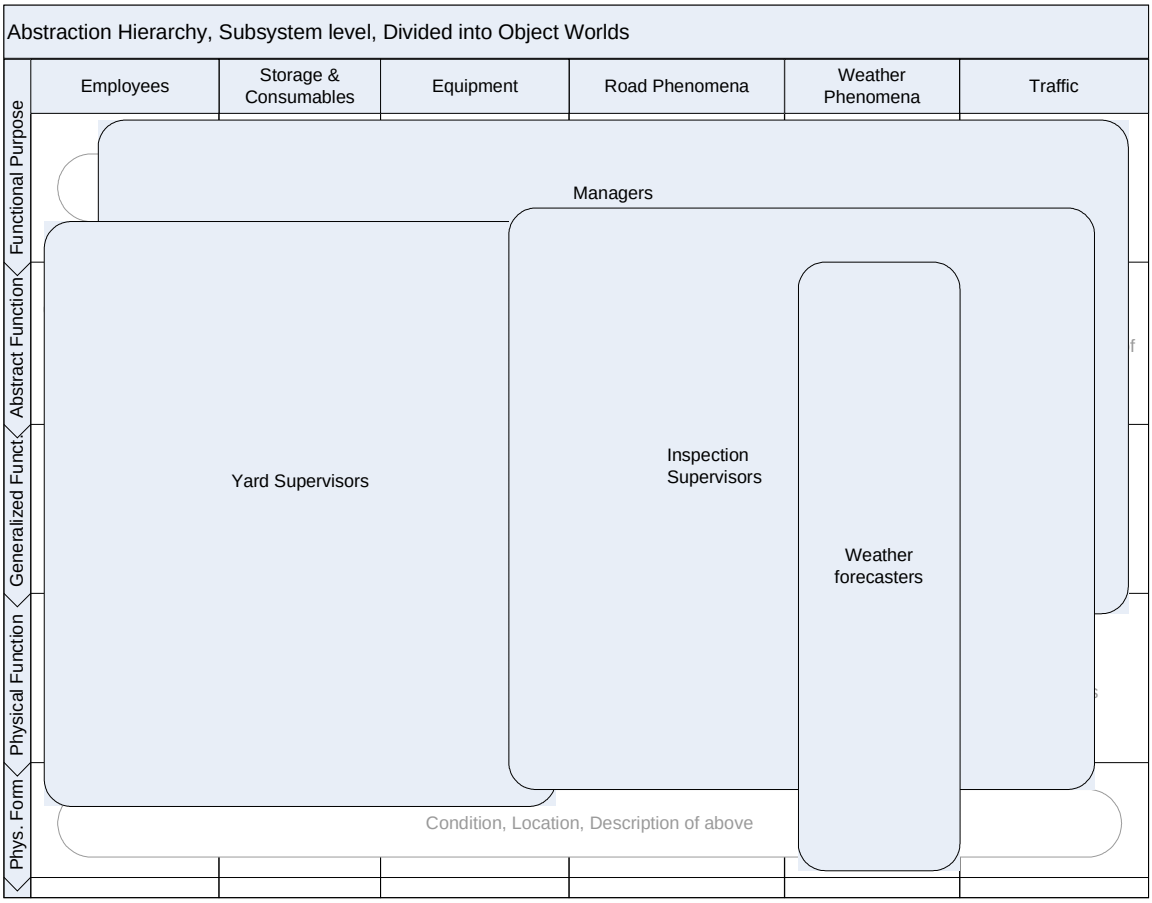
Strategy	Cannot Be Used If…	Performance Factors				Functional Purpose Tradeoffs				
		Time Spent	Complexity Of Cognitive Processes	Dependency On Knowledge Of Required Task	Complexity Of Output State Of Knowledge	Environment	Safety	Budget	City Transport	Legal
Select a pre-planned set of beats	...the number of beats to perform is greater than the number of readied equipment and personnel	5	5	5	5	1	4	3	4	4
Select custom subset of pre-planned beats	…the beat is not possible due to work domain changes (road construction)	4	4	3	5	2	4	4	4 to 5	4 to 5
Generate beats with pre-planned procedure templates	…pre-planned procedure templates are not available	2	2	2	4	3	4 to 5	3 to 5	3 to 5	3 to 5
Generate freeform custom routes	N/A	1	1	1	1 to 3	2 to 5	1 to 5	1 to 5	1 to 5	1 to 5

Appendix C - 5 Strategy Analysis using the Second Approach for Formulate Procedure Activity in De-Icing Task

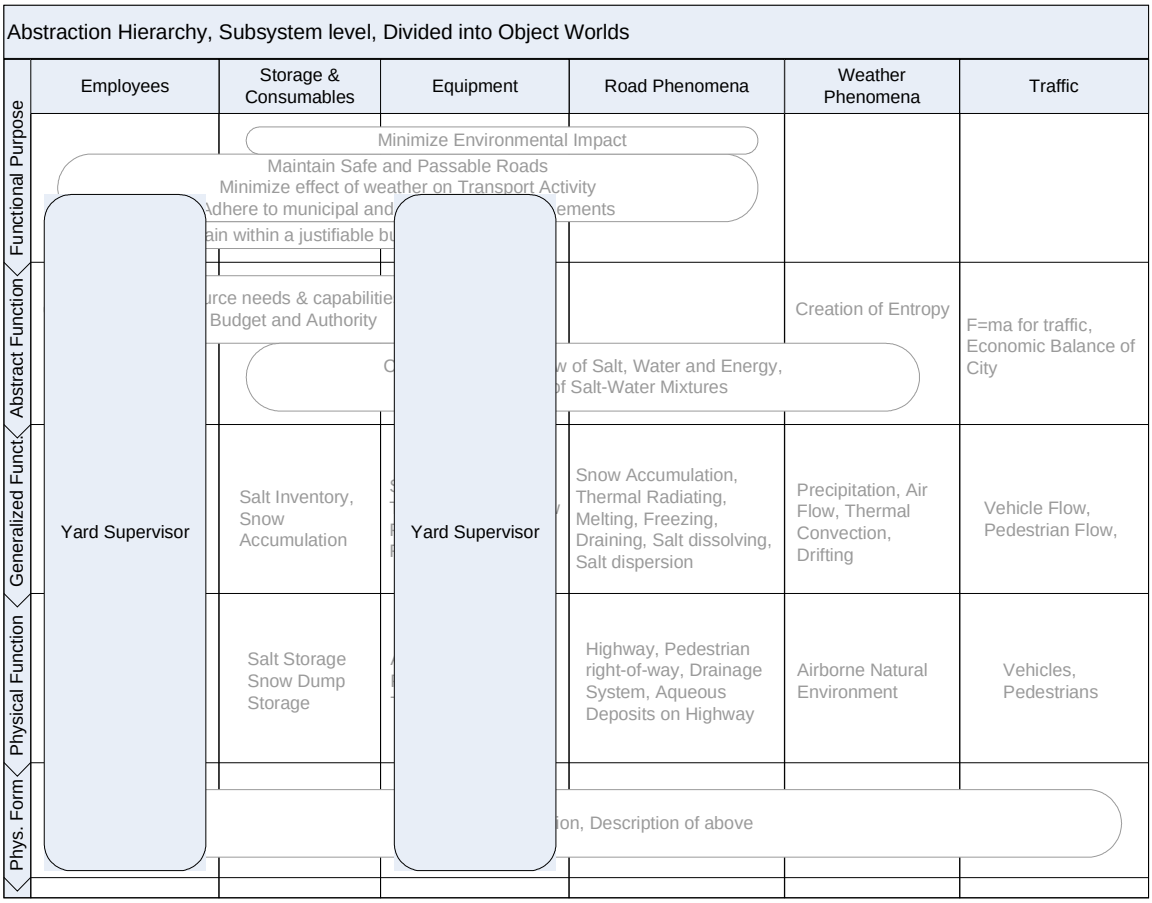
13. APPENDIX D – SOCIO-ORGANIZATIONAL ANALYSIS FIGURES

INFORMATION SOURCE	INFOMRATION RECEIVER: Operators, drivers, labourers	Winter contract inspectors	Maintenance inspectors	TMC dispatch	Supervisors (roads & sidewalks)	Supervisors (contract inspection)	Supervisors (communication)	District Co-ordination Centre staff	Superintendents (Roads & Sidewalks)	Superintendents (Technical Operations)	District Managers	Road Operations Manager	District Director	General Manager	Central Co-ordination Centre staff	Director Transport Services	Weather provider	Meteorologist	Call center (416-388-SNOW)	External actors (councillors, TTC, WES, Access Toronto, etc.)
Operators, drivers, labourers	radio, (direct)	radio	radio	radio	radio, direct?															
Winter contract inspectors		radio, cellular		radio, telephone		paper form, direct?														
Maintenance inspectors				radio		paper form, direct?														
TMC dispatch	radio	radio	radio		radio?	radio?	radio?													
Supervisors (roads & sidewalks)	direct?, radio?				cellular, paper form	cellular	cellular		direct?, email?									telephone		
Supervisors (contract inspection)		direct?, radio?	direct?, radio?		cellular	cellular	cellular			direct?, email?								telephone		
Supervisors (communication)					cellular, snow advisory	cellular, snow advisory	cellular, snow advisory	direct, snow advisory	snow advisory	direct?, email?, snow advisory	snow advisory	snow advisory	snow advisory	snow advisory	snow advisory	snow advisory		telephone	telephone?	snow advisory, telephone
District Co-ordination Centre staff							direct	direct, phone to other districts?				email	email	email				telephone		email
Superintendents (Roads & Sidewalks)					direct?, email?				conference call, cellular, Blackberry	conference call, cellular, Blackberry	conference call, cellular, Blackberry							telephone		
Superintendents (Technical Operations)						direct?, email?	direct?, email?		conference call, cellular, Blackberry	conference call, cellular, Blackberry	conference call, cellular, Blackberry							telephone	telephone?	
District Managers									conference call, cellular, Blackberry	conference call, cellular, Blackberry	conference call, cellular, Blackberry		conference call					telephone		
Road Operations Manager																		telephone		
District Director											telephone?, email?							telephone		
General Manager																		telephone		
Central Co-ordination Centre staff																		telephone		
Director Transport Services																				
Weather provider		printout			email, website				email, website		email, website									email, website
Meteorologist																				
Call center (416-388-SNOW)																				
External actors (councillors, TTC, WES, Access Toronto, etc.)																			telephone	

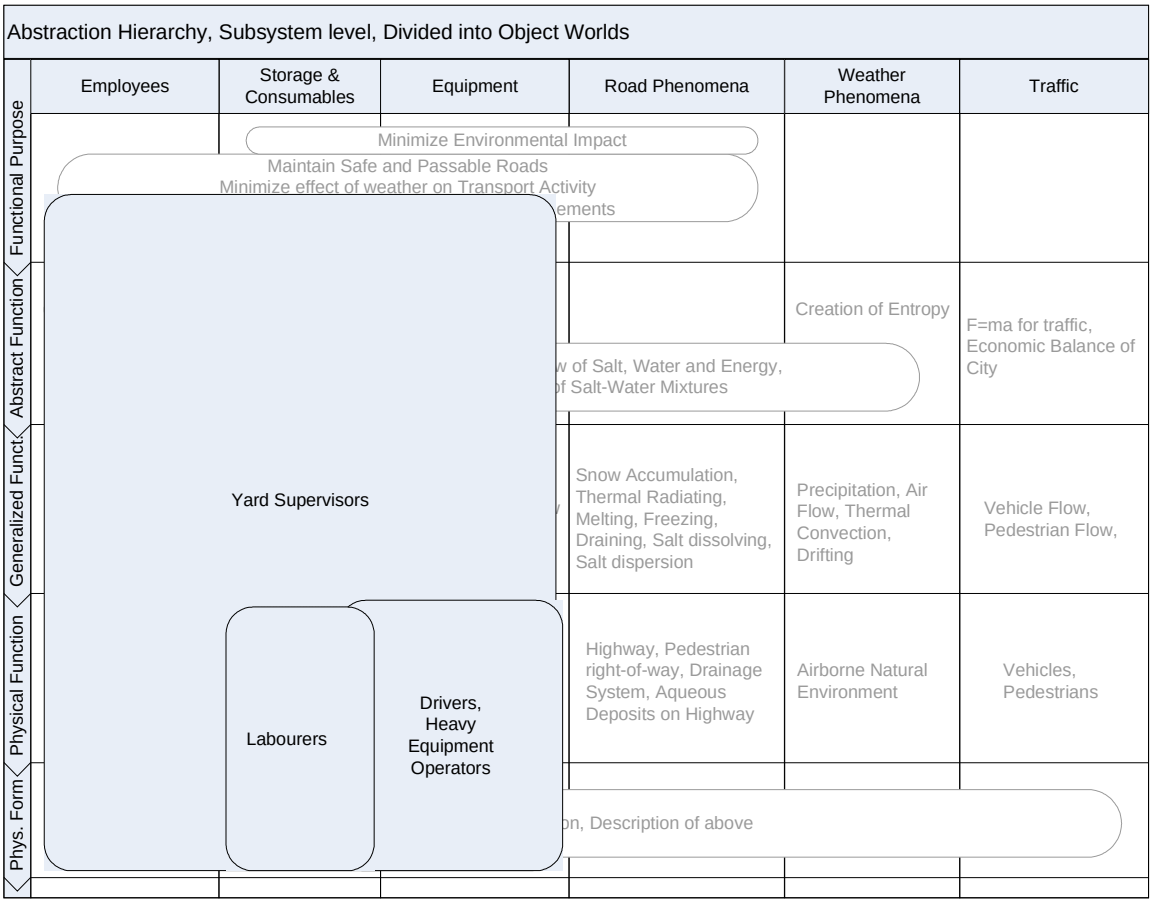
Appendix D - 1 MWMP Communication Matrix



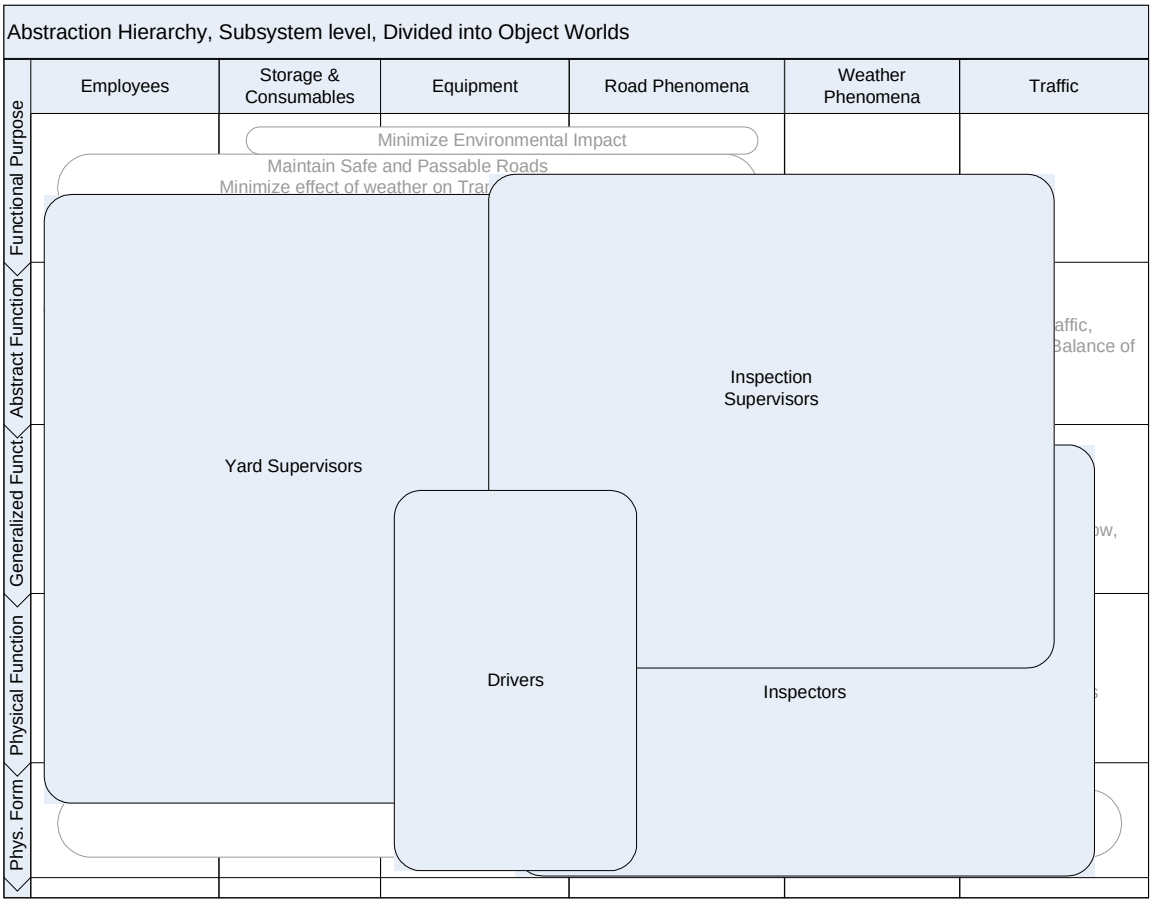
Appendix D - 2 Mapping of actors during Planning, Forecasting and Call Center



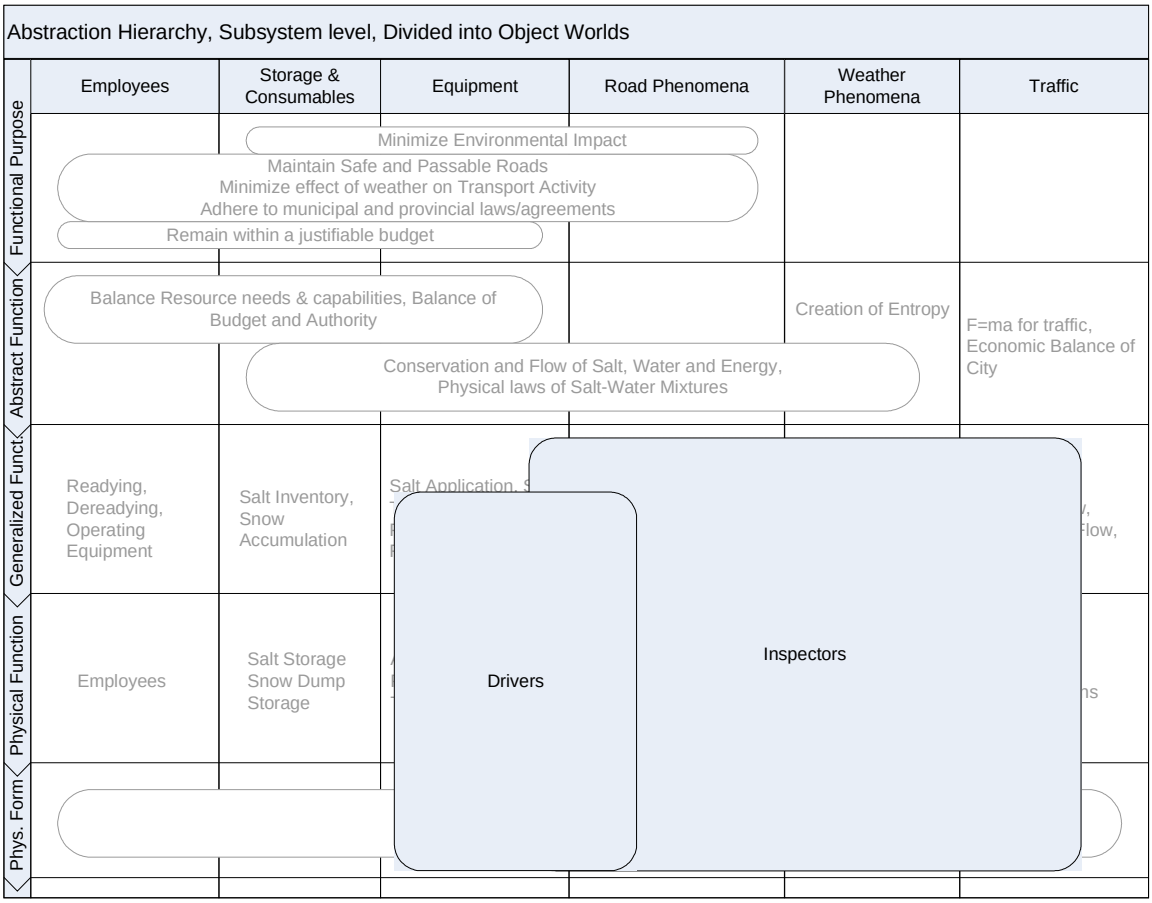
Appendix D - 3 Mapping of actors during Deploying Personnel



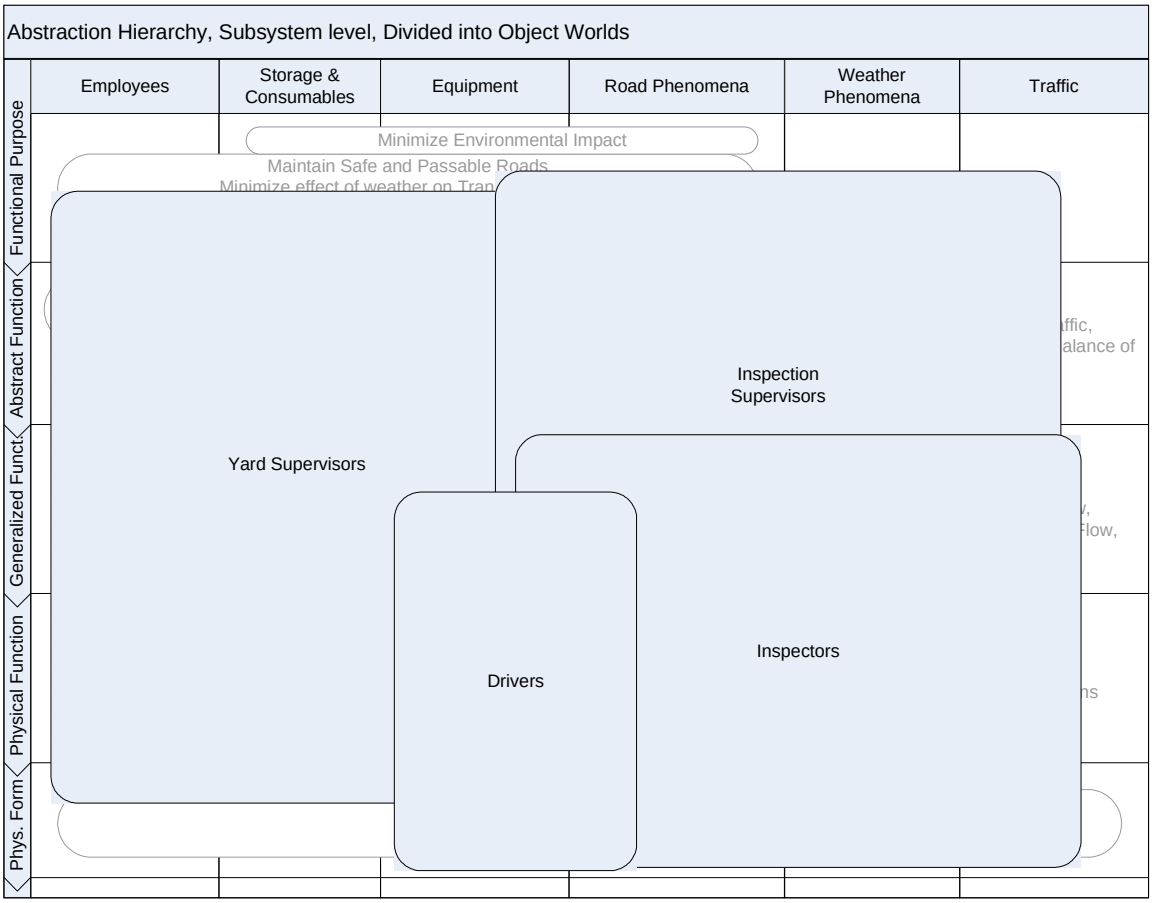
Appendix D - 4 Mapping of Actors during Preparing Equipment (Readying) and Maintenance



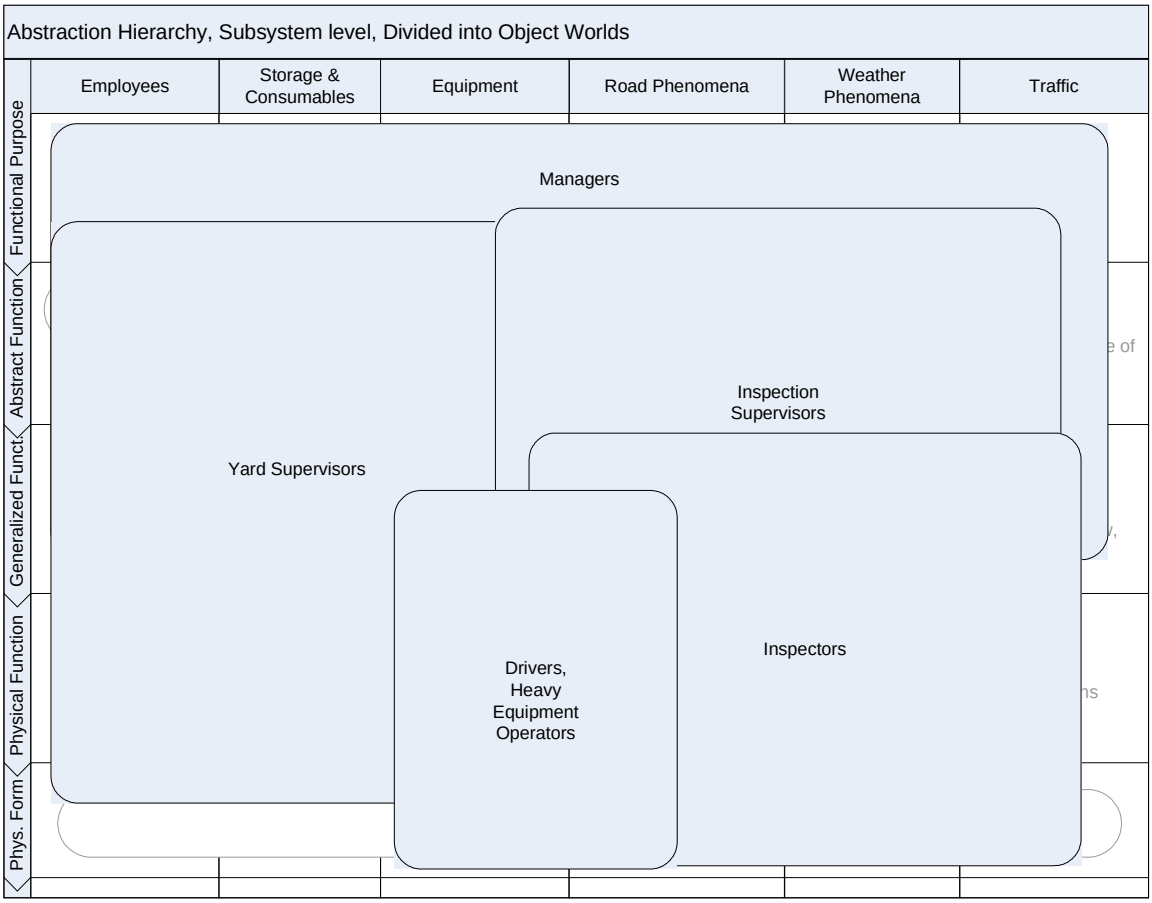
Appendix D - 5 Mapping of Actors During Anti-icing



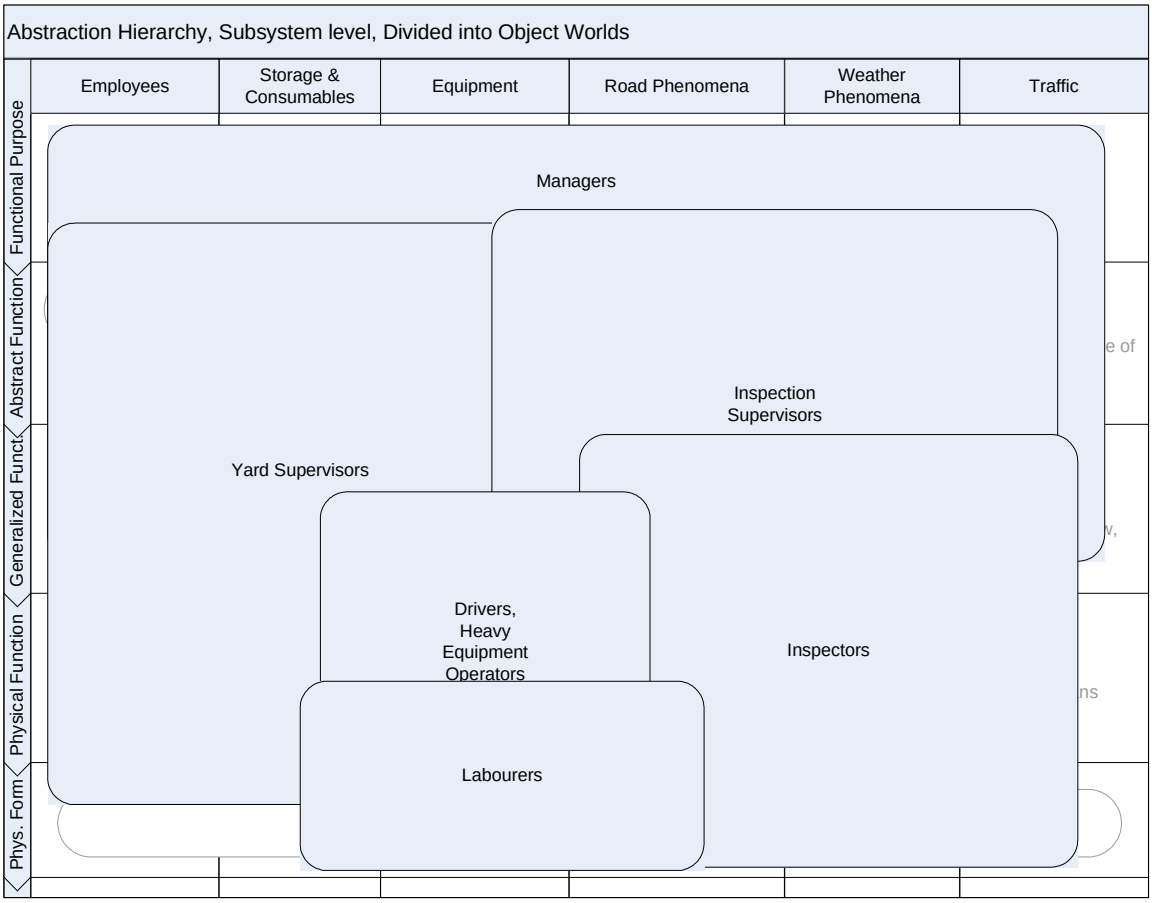
Appendix D - 6 Mapping of Actors during De-icing (1st round)



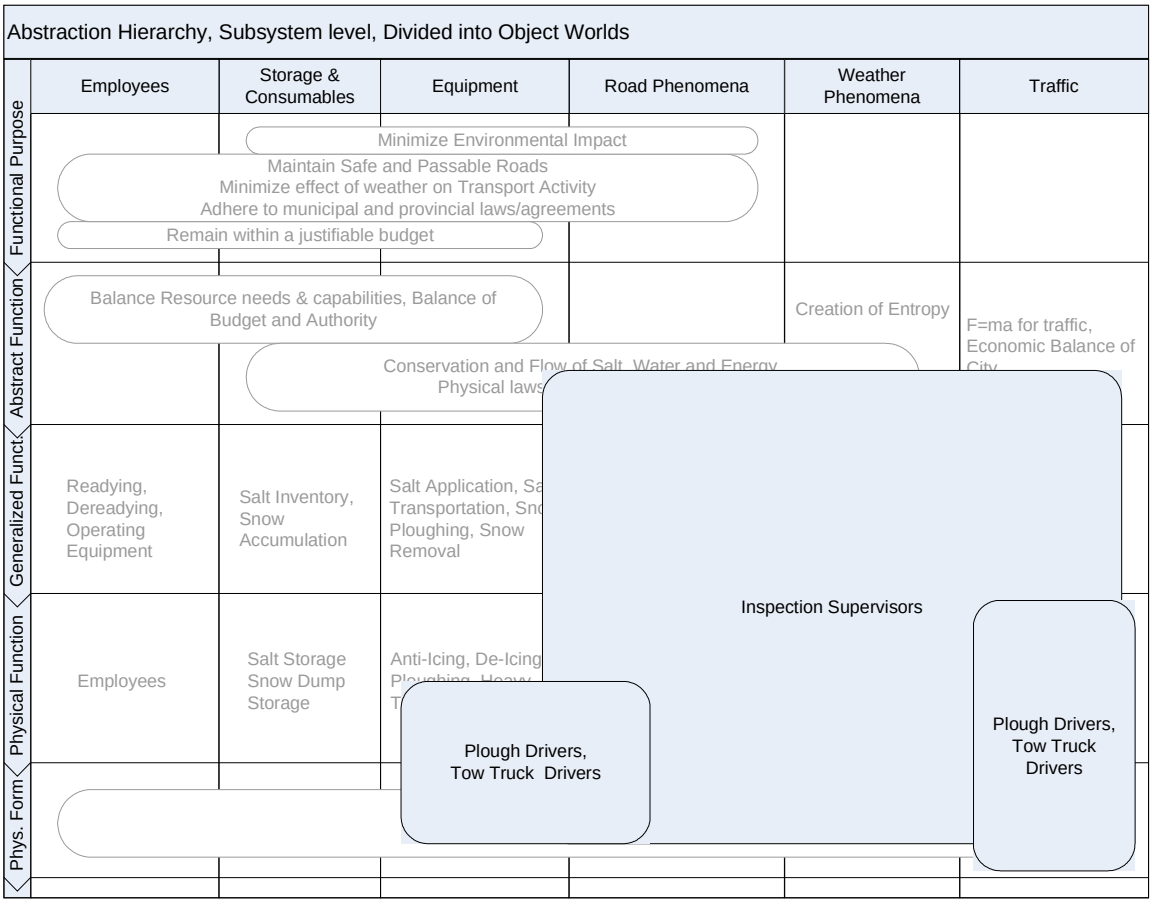
Appendix D - 7 Mapping of actors during De-Icing (subsequent rounds)



Appendix D - 8 Mapping of actors during Ploughing, Sidewalk Salting & Sanding and Driveway Windrows



Appendix D - 9 Mapping of actors during Snow Removal



Appendix D - 10 Mapping of actors during Friendly Towing