PART I - AVALANCHE EXPERTS' JUDGMENT AND DECISION MAKING

Laura Adams
Selkirk College and the Selkirk Geospatial Research Center, Castlegar, BC.
ladams@selkirk.ca

INTRODUCTION

A growing body of research indicates significant enhancements can be achieved in decision quality and decision skills learning programs for decision-makers of all levels through the study of how experts make decisions in real-world settings. This article is the first installment of a three-part series from my Masters Degree research in human factors and expert decision-making. Part I identifies and describes the judgment and decision processes that avalanche experts use to solve the decision problems they face in their profession. In Part II, I will discuss the human factors that influence avalanche experts' ability to make sound judgments and decision actions. In Part III, I will examine these findings in light of recent advancements in strategies for decision skills learning, decision support, and effective avalanche accident prevention.

PART I HIGHLIGHTS

- Avalanche decision-making occurs at the center of three systems of influence: human, physical, and environmental.

- Current information relevant to the three systems of influence is critical for sound judgment and decision actions.

- As avalanche decision-makers gain knowledge and experience, they develop more expansive mental models and use increasingly higher levels of decision complexity.

- The level of expertise of the decision-maker, the systemic context of the situation, the degree of time pressure, and the level of uncertainty within the human, physical, and environmental systems of influence determine the application of decision modes.

- Avalanche experts use the decision strategies of pattern recognition to make effective judgments, and processes of critical thinking and mental simulation to analyze whether their judgments are accurate and if their planned actions will work.

- Metacognition and situation awareness are integral to objective and sound decision-making, and offer powerful strategies to counter the influence of potentially dangerous biases and heuristic traps in the decision process.

- Effective communication within teams results in higher-quality decisions by adding collective knowledge, information, resources, and diverse perspectives to the decision process.

METHODS

To derive an understanding of avalanche experts' decision processes and the human factors that influence their decisions, I used Naturalistic Decision Making (NDM) and Cognitive Task Analysis (CTA). NDM examines the kinds of cognitive skills, knowledge, and experience that are involved in avalanche experts' real-world problem solving and decision-making. CTA seeks to capture this expertise, and make it accessible for decision skills training and support.

I collected data in two phases during my research. In the first phase, I used an electronic survey, and in the second, I facilitated two avalanche experts' focus groups. Using a retrospective case-based method known as the Critical Decision Method, I asked Canadian avalanche experts' to "describe your most significant avalanche decision-making experience, including how experience, knowledge, skills, and human factors influenced your decision." Their stories are woven throughout this article.

Thirty-seven Canadian avalanche professionals participated in my research, representing 12% of the 314 professional members of the Canadian Avalanche Association (at the time the research was conducted). Participants represented a cross section of Canadian avalanche industry expertise (Figure 1) and possessed an extensive experience base (Figure 2). Eighty-nine percent of the participants were male, and 11% were female.
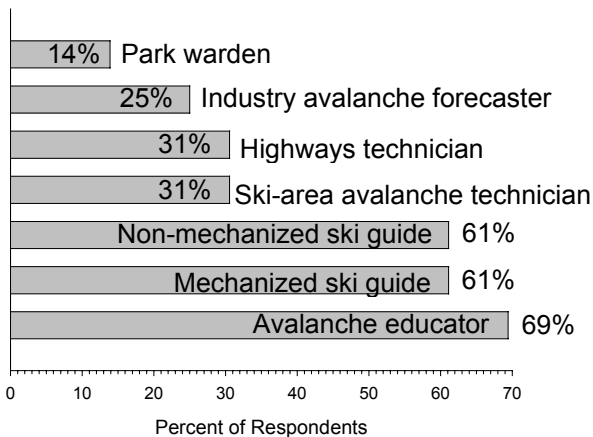

Figure 1. Area of expertise in the avalanche industry.

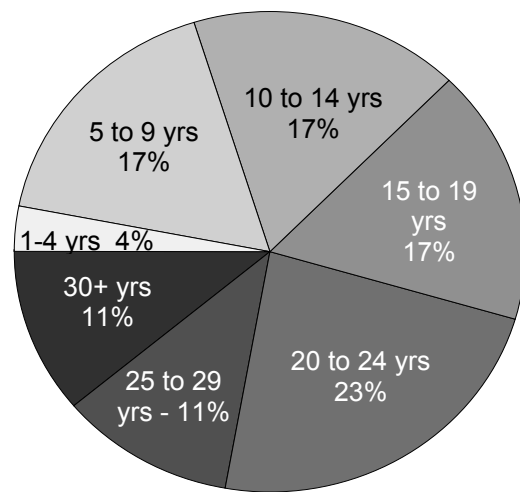Note: Numbers total greater than 100 as most participants had several areas of expertise.

Figure 2. Years of professional experience working in the avalanche field.

A SYSTEMS PESPECTIVE OF AVALANCHE DECISION-MAKING

Avalanche-related decision-making occurs at the centre of three systems of influence; human, physical, and environmental (Figure 3). Since human behaviour is best understood in the social and natural frameworks in which it occurs, sound judgments and decisions cannot consider one of these systems in isolation. Understanding the inter-relationships between these phenomena requires a systems thinking perspective.

The avalanche decision-making process involves making complex judgments about current conditions and the level of uncertainty within the three systems of influence. It then requires making critical decisions regarding what actions will be taken. These judgments and decisions occur within a dynamic process, and are embedded within a broad situational (terrain, snowpack, weather) and human context. Therefore, avalanche-related decisions are not made as discrete events or isolated moments of choice. Understanding the context that surrounds the decision process is essential.
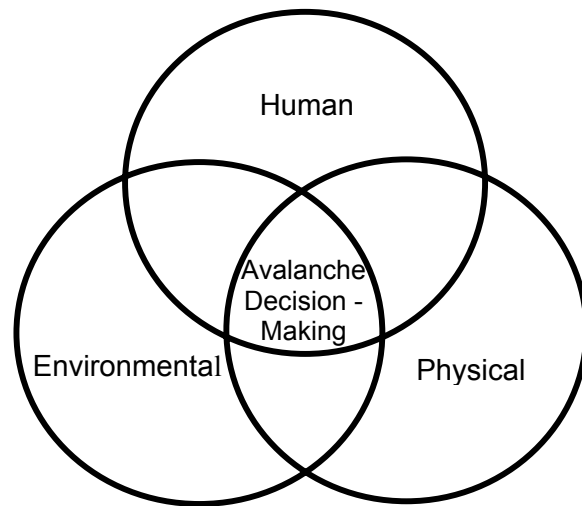

Figure 3. Systems of influence in avalanche decision-making.

Note: The human system contains the individual, team, client, organizational, and socio-political realms. The physical system contains the terrain, including geographic location, slope aspect, angle, shape, and ground cover. The environmental system contains the snowpack and the weather conditions that create it and influence its instability.

FOUNDATION OF AVALANCHE JUDGEMENT AND DECISION EXPERTISE

Three themes emerged as the critical foundation of these avalanche experts' capacities for making sound avalanche-related decisions:

1. Experience

Experience lies at the heart of sound avalanche-related decision-making and

results in superior knowledge, skills, and information processing capacities. A helicopter ski-guide described this phenomenon stating, "experience is a huge factor in avalanche decision-making, as the accumulated mileage gives me a conscious and unconscious base of knowledge which to draw from." Participants described how they accumulated avalanche experience over the years, and in different geographic regions and snow climates. For example, one expert explained, "exposure to a variety of regions and snowpack conditions helps round out my thinking. When I encounter coastal conditions in the Rockies, or buried facet layers in the Coast range, I can adapt my thinking and decision- making based on what I'm observing at the time."

This finding is consistent with literature on experiential learning and expertise that suggests key characteristics of expert's performance are acquired through experience. For example, Dave McClung from the University of British Columbia suggests experience is fundamental to objective avalanche decision-making, not only to accurately evaluate the snowpack, but also to aid complex decisions and avoid dangerous human biases.

2. Knowledge and Skills

Past experiences blend together to build a knowledge base that enables experts to make sense of current situations and conditions. As one participant stated: "Knowledge is the accumulation of experience, for example, the association of a particular slope angle to its likelihood of sliding in certain conditions, or the influence of wind and snow deposition on slab formation when the air temperature is at a certain value." Experts in my study described how their experiences enabled them to understand and practically apply the knowledge and skills they had gathered throughout their industry training and professional development programs. For example, a ski-area avalanche forecaster related to me how he used his knowledge during a difficult avalanche control mission in unusual conditions: "Thankfully our skills learned through training and experience aided us to place ourselves in a location that reduced our likelihood of becoming involved in the avalanche. I believe this action saved our lives."

3. Information Relevant to the 3 Systems of Influence

Having information and data relevant to the human, physical, and environmental systems of influence was the third element in the foundation to avalanche experts' decision-making success. Participants discussed the critical importance of having a "data-rich environment" in which to support their decisions. Their stories included extensive references to the need for relevant current and historical information in the decision process, for example, site-specific snowpack data, influencing weather conditions, nearest neighbour observations, client information and history, organizational logistics, and culture.

MENTAL MODELS

Mental models are internal representations that portray the avalanche domain and drive our processes of understanding. Experiences and knowledge events specific to the avalanche field result in the creation of these highly integrated knowledge structures. A senior avalanche forecaster for highways emphasized the extent to which mental models aided his decisions: "The success of that week [of avalanche forecasting and control] of

very large, continuous avalanches was based in my knowledge of the terrain and how it performs in a storm such as this."

Rich mental models provide the decision maker with knowledge of the relevant elements of the decision problem, a way of integrating these elements to form meaning, and a system for using this understanding to project future states. These mental models guide avalanche experts to the most important aspects of the decision problem and filter out irrelevant information. The use of mental models results in reduced information management, since the avalanche expert does not need to process all of the available information in order to make an effective decision. When faced with a situation requiring decision action, the avalanche expert employs his or her mental model and it is immediately obvious what decision options make sense.

AVALANCHE EXPERT JUDGMENT AND DECISION MAKING MODES

As avalanche decision-makers develop more expansive mental models, their thought processes evolve in qualitatively new ways of thinking and knowing, and they use increasingly higher levels of decision complexity. Initially, judgment and decision actions are rule-based and include an increasing use of analytical processes. As they gain knowledge and experience, intuitive decision-making becomes more prevalent and important. I suggest that when avalanche decision-makers are able to recognize subtle perceptual cues, and maintain a constant awareness of the current conditions within the human, physical, and environmental systems of influence, they have evolved into systems thinking processes.

Therefore, avalanche decision-makers evolve through a hierarchy of judgment and decision-making complexity (Figure 4). This hierarchy can be seen as a continuum where higher levels of judgment and decision capacities incorporate the lower one(s).
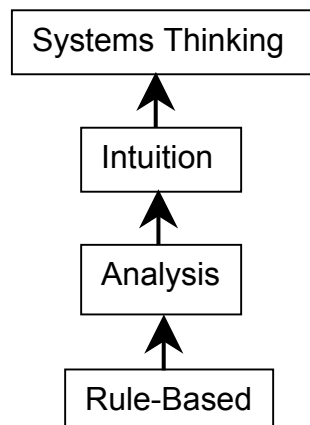
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Figure 4: Hierarchy of avalanche judgment and decision-making complexity.

Rule-based processes are consciously controlled by a stored rule or procedure, for example, standard operating procedures carried out in pre-identified conditions or situations. **Analysis** utilizes a conscious process of reasoning that requires time and deliberate effort. For example, analyzing synoptic-scale weather and snow pack information, and then considering local conditions and observations in order to make snow stability and terrain use determinations. **Intuitive** decision-making pre-consciously utilizes the mental models and extensive repertoire of patterns that we accumulate and refine over years of experience. Sets of perceptual cues are unconsciously organized and grouped together to form patterns or 'knowledge chunks'. In a future situation, when a few of these cues are noticed, we know that we can expect to find the others. We recognize the situation as familiar by matching it to a pattern encountered in the past, including the associated routine for responding with action. As we acquire more patterns and strategies, our expertise increases. It becomes easier to make complex decisions, since we see new situations with a sense of familiarity and recognize how to act (see Klein, 2003). **Systems Thinking** integrates a holistic awareness of the human, physical, and environmental systems of influence.

Ninety-five percent of participants reported using intuitive processes in their critical decision summaries. In 83 % of these cases, intuitive decision-making was the primary mode of cognitive (thought and understanding) function used. This finding is consistent with the literature on high stakes decision-making that identifies intuition as the primary decision mode used by experts in natural settings. Intuition alerted these avalanche experts' to recognize potentially dangerous situations, such as the ski area forecaster who explained to me: "I had this compelling hunch the whole snowpack was about to let go." Intuition also signalled the need for analytic processes when faced with situations of uncertainty. For example, one expert stated: "I tend to know if my choice is acceptable. If the consequences are serious, I feel a niggling doubt or 'gut feeling'. Then I'll try to get more information and usually the right choice becomes evident."

APPLICATION OF DECISION MODES

The level of expertise of the decision-maker, the systemic context of the situation, the degree of time pressure, and the level of uncertainty within the human, physical, and environmental systems of influence determine the application of these modes. These modes complement one another to produce effective decision actions. For example, when avalanche forecasting (e.g. office-based morning meetings), these experts had more time and information resources available, and used analysis as their primary mode of decision-making. While in high-stakes, time-pressured field decisions, intuitive processes prevailed. In any situation, when these experts encountered decision problems that rule-based or intuitive processes were unable to handle, they shifted to analytic processes. This included, where time-permitted, consultation with other team members.

While I suggest the primary mode of decision-making is determined by these variables, it is important to note that one process did not completely exclude the others. My study findings concur with the work of other research that suggests single decision problems are often solved using different modes, even though one mode may appear to be more dominant. For example, an avalanche expert may use systems thinking and intuitive processes for the parts of a problem for which adequate knowledge and mental models exist, while rule-based or analytic processes may be used to solve other parts of the

problem. I noticed these experts often used the non-primary mode as a quality control check, such as in the case of a ski-area forecaster who described the morning analysis process and then stated: "The final point is – how do I *feel* about it?" Similarly, analysis was often used to check intuitive decisions as a gauge to whether the intuition was based in knowledge and informed experiences, or potentially misleading biases.

DECISION STRATEGIES

The avalanche experts in my study used the following decision strategies:

1. Pattern Recognition

A majority (88%) of the participants reported pattern recognitional processes in their critical decision summaries. For example, one expert stated: "As time goes by I am able to spot the trends of events that are leading down the dark road of a difficult decision." Pattern recognition enabled these experts to make sense of a situation by comparing it with their past experiences, or by seeing subtle relationships between the complex factors that were influencing the current situation. These experts also recognized when things were abnormal. For example, recognizing patterns and critical anomalies was the key factor that enabled one forecaster to provide critical advice to the leaders of another group to change their trip location from the area they had planned to ski-tour the next day: "My knowledge of current and building conditions in the area led me to think about the lack of releases on these north faces, and that the possibility of them coming down was high." Later that morning, a massive avalanche released on that north-facing slope, in the exact area the group had originally planned to be.

2. Mental Simulation

Mental simulation is an envisioning strategy where decision makers use their imagination to construct a sequence of events to observe the outcome. This strategy was utilized extensively by participants in my study (76%). For example, one expert related: "The question of 'what if' occurs every time I come across avalanche terrain. For me, assessing the consequences is very important in my decision making and determines my perception of risk on the terrain." Another participant emphasized how effective the application of mental simulation is in complex decision-making, as "the same terrain cannot be treated in the same way since snow conditions are constantly changing." Mental simulations enabled these avalanche experts to analyse the potential results of a decision action and revise their plan as necessary.

Two recent tools that facilitate mental simulations offer great promise to support sound decisions. Alex Van Herwijnen & Bruce Jamieson's research describing the characteristics of avalanche fracture suggests using descriptive information to characterize the triggering potential and characteristics of avalanches. For example, a sudden fracture that crosses the entire column and easily releases the overlying block (sudden planar) provides a visual indication of the fracture character that can be extrapolated to simulate the potential and type of avalanche release in surrounding terrain. Roger Atkins recently proposed an avalanche characterization checklist that defines avalanche regimes and their associated risk management strategies. An increase in the awareness of the character and distribution of likely avalanches, for example, large, dry, deep slabs on basal persistent weak layers, can be translated

directly into improved terrain management.

3. Critical Thinking

We think critically when we apply standards to our thought processes, such as raising vital questions, analyzing self and peer assumptions to determine whether they are justified, evaluating other points of view, or examining the reasoning process for consistency in interpretation when drawing conclusions. Eighty-five percent of the critical decision summaries in this study included descriptions of critical thinking. For example, an avalanche forecaster was preparing terrain for an international extreme ski event. His snowpack assessment resulted in significant concern due to the presence of a deep snowpack instability. However, after conducting extensive explosive control and observing helicopter skiing in the adjacent area, there were no avalanche releases observed. Still questioning, he sought additional information from a local helicopter ski group. He related: "the local guides seemed totally unaware of the deep snowpack instability and gave no meaningful feedback." The next morning, one of the slopes had released in a 250 cm deep slab avalanche. He called event management and told them the event was off. In his critical decision summary he explained, "it is easy to say YES and have your clients love you. I am ultimately paid to say NO, and that is the hardest of decisions, but so far has never been the wrong one." Several weeks later, the entire helicopter skiing industry in that region cancelled the remainder of their season due to snow stability concerns.

SITUATION AWARENESS AND METACOGNITION

It is widely recognized by high-stakes decision researchers that situation awareness and metacognition are fundamental to sound decision-making. My research supports this idea. **Situation awareness** (SA) is our capacity to maintain an accurate perception of our external environment by detecting the source and nature of problems and situations that require attention. Decision researcher Mica Endsley argued that situation awareness involves much more that simply perceiving information in the environment. It requires understanding the information in relation to the decision-makers goals, and then projecting the future states of the environment. Metacognition extends SA to our internal environment, and is a higher-order of judgment and decision making complexity related to systems thinking. **Metacognition** (mindfulness) is our knowledge of, and ability to control, the state and process of our mind. It has also been described as our ability to take our own strengths and limitations into account.

A ski-touring guide described using metacognition as a regular process in his decision-making: "I take the time to absorb the surroundings and the mood in the air while my clients get ready. It's a process that I regularly go through, as I like the subconscious approach before I go through my rationale thinking approach." Another participant discussed his use of metacognition as an analytic process to check potential biases arising from affective or social influences stating, "It is valuable for me to understand how I operate under stress and what is motivating the choices I am making. This is important because I find it keeps me honest and allows me to focus on objective conditions rather than subjective opinions or emotions." Metacognition enables decision–makers to be aware of their thought processes and control them appropriately. Thus, metacognitive skills and situation awareness are crucial for proficient problem solving and decision-making.

COMMUNICATION AND TEAM DECISION-MAKING

While an individual decision-maker may bear the final responsibility for the decision action, team members often contributed to the final product. Team environments add information, resources, and diverse perspectives to the avalanche decision problem. Teams operate as knowledge systems, and the building of shared mental models and the collective consciousness of the team mind creates a highly efficient context within which avalanche judgement and decisions can occur. Shared mental models provide a context within which information and tasks can be interpreted, as well as a basis for predicting the needs or behaviours of team members. The results of extensive research indicate that team decision-making is preferred when tasks are extremely complex, as it is unlikely a single individual possesses all of the relevant knowledge with which to discover adequate solutions.

I found the capacity of teams to make effective decisions was a direct function of the quality of interactions amongst team members. Environments that encouraged effective and open communication resulted in improved judgment and decision actions, and reduced subjective biases that may have been present in an individual decision-maker. In addition, effective communication fostered shared mental models regarding goals and conditions between decision-makers and management, resulting in collective understanding and higher levels of support for the decision-maker's judgments and decision actions.

Research indicates high-quality communication is associated with high-quality solutions and team performance. Higher rates of verbalization results in better decision-making, such as task specific information exchange, suggestions of intent, acknowledgements, and disagreements. The importance of communication has been widely recognized in the literature, and along with enhancing predictability, has been identified as the primary method of reducing human error in high-stakes decision-making.

A CONCEPTUAL MODEL OF AVALANCHE EXPERTS' DECISION-MAKING MODES AND STRATEGIES

I constructed a conceptual model that describes the judgment and decision making modes and strategies used by the avalanche experts in my study. This model integrates the elements of judgment and decision-making within a holistic system (Figure 5). In this model, avalanche experts' decisions are made within a systemic process that unfolds from the centre of the system. Experience, knowledge and skills, and information relevant to the human, physical, and environmental systems of influence provide the foundation. The decision strategies of pattern recognition, mental simulation, and critical thinking are driven and fed by this foundation. Through the use of metacognition and situational awareness, avalanche experts are internally and externally aware of the factors that influence their judgments. Effective communication fosters and enhances the quality of their judgments and decisions. Intuitive and analytic decisions result within a dynamic systems thinking perspective.
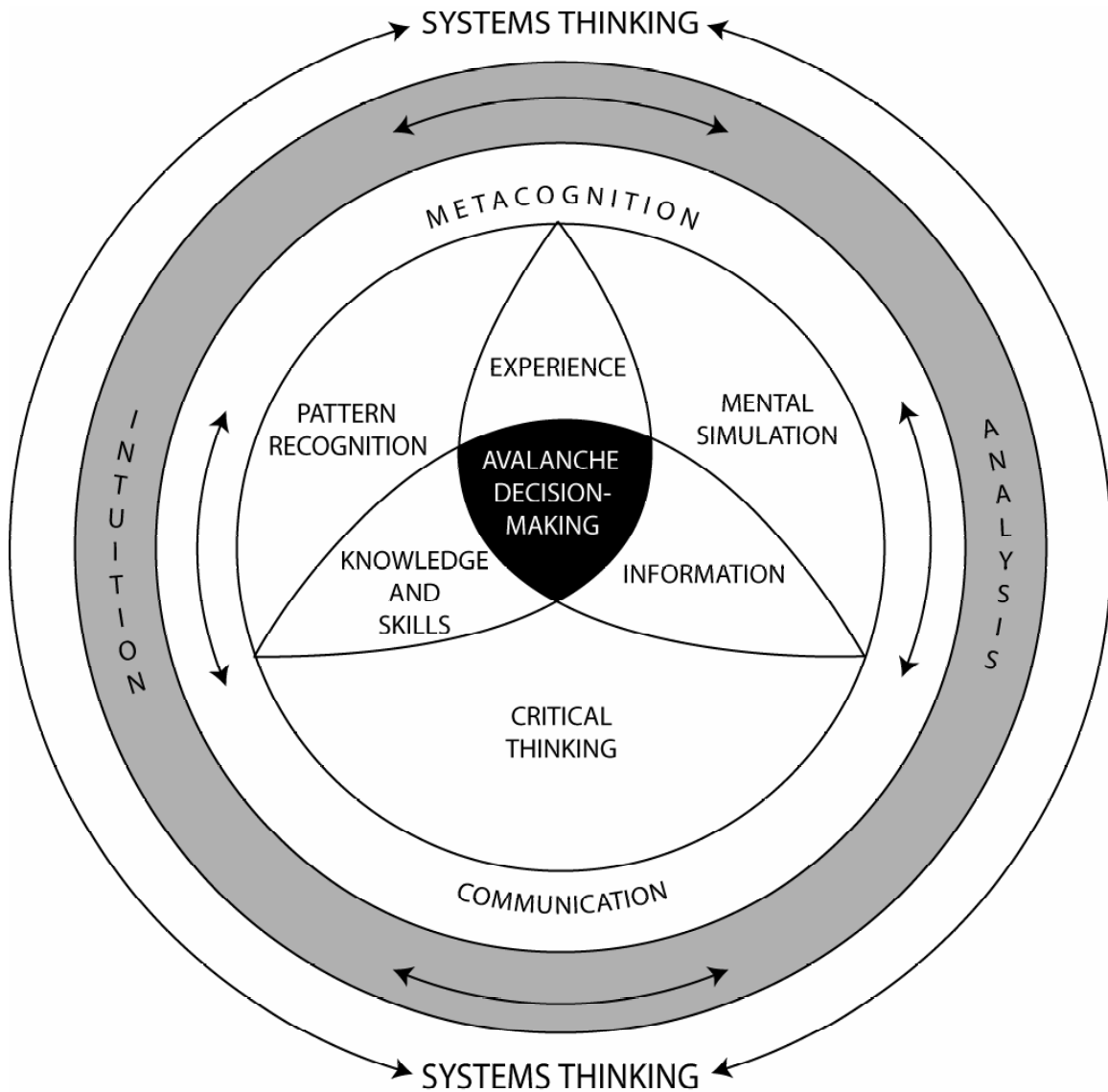
Figure 5. Conceptual model of avalanche experts' decision making modes and strategies.

CONCLUDING REMARKS

A major goal of my research was to decouple the judgment and decision processes of avalanche experts, and to illuminate the decision modes and strategies they use in real-world settings. I suggest that a more complete understanding of these processes, and the systemic factors that influence successful judgments and decisions (Part II), will enable avalanche decision-makers of all levels to significantly enhance their judgment and decision capacities. It is important to note that decision-makers should utilize decision modes and strategies that are appropriate and effective for their level of knowledge and experience, in order to ensure they are making accurate judgments and

sound decision actions. In addition, NDM research suggests the best way to improve decision skills is to learn from how the experts do it. This approach has lead to significant advances in decision-skills learning programs. In Part III of this series, *Developing Expertise in Avalanche Decision-Making,* I describe the key factors in the development of avalanche judgment and decision expertise, and offer an integrated set of strategies to support and enhance decision skills at novice and expert levels.

ACKNOWLEDGEMENTS

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