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Using grounded theory and mental modeling to understand influences on electricians' safety decisions: Toward an integrated theory of why electricians work energized

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ABSTRACT

Why people engage in unsafe work practices, especially when advised not to, is an important question about human and organizational behavior. We seek insights into such behavior by examining questions about electricians' safety decisions, with focus on why electricians work "energized" (or "live" meaning with electrical energy on) even when safety standards call for de-energizing. Using a grounded theory approach augmented by a mental models methodology, we develop from literature and 19 experts an 'expert model' of influences on electric worker safety decisions. From 60 in-depth electrician interviews we develop an integrated theory, summarized in a decision tree, describing key influences, decisions and events leading to energized work. Findings show electricians' work is cognitively demanding. Working energized is not a simple yes/no choice, but instead is a decision influenced by many task, worksite, individual, organizational, and external factors. Working energized may better be thought of as an outcome arrived at via several pathways, including paths that lead to unknowingly working energized. Each path to knowingly or unknowingly working energized suggests different interventions to reduce risk. Additional key findings include that some electricians omit hazard assessments, perceive that past work by people not trained in electric work increases risk to electricians, and sometimes must negotiate to achieve prioritizing safe work practices over time or production pressures.

"In my day-to-day job, we are working with something that you can't see, can't touch and you rely on the people ahead of us to have done the job right. So, even walking into a situation, it's hazardous." - Ontario Electrician

1. Introduction

A concern in many organizations, especially those that regulate or employ people in high-risk occupations, is why people engage in behaviors they know to be unsafe and what can be done to prevent such behavior. Electrical work is one example of such a high-risk occupation; there is evidence that even highly-trained electrical workers sometimes knowingly take unnecessary risks that increase the chance of electrical occupational injury (EOI) to themselves or others.

Electrical work is evidently dangerous. Electrocution is one of the top six causes of occupational deaths in Canada and the U.S. (Canadian Standards Association, 2012; U.S. Department of Health and Human Services, 1998). Between 1992 and 2002 there were 3378 fatal EOIs in the US, over 29,000 non-fatal electrical shocks, and about 18,000 non-fatal electrical burn injuries resulting in lost days of work (Cawley and Homce, 2008). Electricians are at especially high risk. Thirty-one percent of EOI fatalities in the U.S. are electricians (Cawley and Homce, 2008). A survey of over 2000 Swedish electricians revealed that 54% have experienced an electrical injury (Rådman et al., 2016); 65% who had been injured reported at least two severe electrical injuries and 12.5% reported at least ten injury incidents. Nearly 2/3rds of 61 non-fatal EOIs to construction workers seen at a US emergency room were electricians (McCann et al., 2003).

Electricians are highly trained to be well advised of the dangers in their work. Safety standards advocate hazard analyses, de-energizing in almost all situations, proper grounding, use of lockout/tagout procedures, and using personal protective equipment (PPE) to prevent or minimize injury (Canadian Standards Association, 2012; National Fire Protection Association, 2014). Yet many appear to choose not to apply

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these safeguards, at least some of the time. In Ontario, 70% of fatal EOI is attributed to use of improper procedures or human error (ESA, 2014). A study in Finland found that most electricians' electrical accidents were attributable to failure to de-energize, test voltage, ground, or protect against exposure to nearby energized wires or equipment (Tulonen, 2010). And, a study of EOI resulting from arc flash/blast in U.S. mines suggests that decisions by experienced electrical workers to not de-energize or to take other shortcuts are behind many incidents (Kowalski-Trakofler & Barrett, 2007).[1]

Electrical injury results from direct contact with wires or objects carrying electrical energy (electric shock/electrocution) or from indirect contact due to electrical arcing. A decision to not work energized, then, eliminates the greatest component of EOI risk.[2] This makes decisions related to working energized a natural focus for preventing EOI to electric workers – and for a study like ours. (Working energized is also known as 'working live', i.e., on live wires). Working energized presents as the result of an apparently singular decision to engage in a behavior obviously assocated with the largest component of EOI risk. Safety standards advise that working energized is only appropriate if working de-energized introduces increased risk (a rare situation), when the task cannot be completed without working energized (also rare), or when energy is at less than 50 V (Canadian Standards Association, 2012; National Fire Protection Association, 2014). Concerns about electric worker decisions to work energized led the Electrical Safety Authority (ESA) to launch a "Don't Work Live" campaign several years before this research, involving posters and other communications directed at Ontario electric workers.[3] Despite the campaign, ESA data shows that the number of electric workers suffering fatal EOI in Ontario remained fairly stable (ESA, 2014). This perplexing reality suggests that the apparently singular nature of the decision to work energized conceals not-very-singular complexities, which have not been adequately surfaced in past research.

It has long been observed that when empirically investigating occupational injury events, investigations often stop with identifying easily observable, immediate causes of the event – unsafe conditions, unsafe acts, or chance variation – and that this leads to blaming victims, and not investigating further to determine root causes (Hofmann and Stetzer, 1998; Holden, 2009; Jørgensen, 2016). The common thread in complaints about such investigations is that methodologies used to investigate injury-causing events provide little or no insight into influences on the unsafe choices and behaviors that contributed to those events, and so offer no insight into how to change decisions, behaviors, and thus, outcomes. Jørgensen suggests a need for structures that link factors in a causal chain to make clear to individuals their own roles in causing or preventing accidents, while also illuminating other causes. Such structures would, it seems, need to delve deeper than the immediate, directly observable causes of events to explore the reasoning of actors who engage in unsafe behaviors.

The ESA desired research into influences on electric safety decisions generally, and most importantly, into *why* electricians work energized. ESA wanted to go beyond the limitations of past studies and understand what lies behind unsafe decisions and actions in order to have a better basis for developing policies and communications to change behaviors and achieve better safety outcomes in Ontario. To this end, we combined a grounded theory approach (Corbin and Strauss, 1990; Glaser and Strauss, 1967) with a *mental models* methodology (Morgan et al., 2002) to achieve access to deeper influences on the behaviors of interest, and develop an integrated theory of the key decisions and events that lead to electricians working energized.

Well-tested and widely used in behavioral science, mental models methodologies use in-depth interviewing and other elicitation techniques to develop representations of the interrelated beliefs – i.e., the mental models – that influence decisions and behaviors. Situations people encounter are interpreted through the lens of their mental models (Johnson-Laird, 1983). These develop over time, and are based on values, priorities, experiences, observations, formal education, training and received communications.

Mental models research methodologies are designed to provide insight into why people behave as they do, often as a basis for developing evidence-based communications or interventions to change behavior (Bostrom et al., 1994; Downs et al., 2004; Morgan et al., 2002; Wood et al., 2017). Several mental models studies have been conducted in the domain of occupational health and safety (e.g., Cox et al., 2003; Lingard et al., 2015; Ng and Chan, 2017; Prussia et al., 2003). In our study, the approach adds to the methodology of grounded theory by providing a systematic means of bringing into view the cognitive processes by which individuals arrive at specific decisions (such as the decision to work energized). This enlarges and enriches the empirical data set that can serve as the basis for grounded development of theory. Others have used a grounded theory approach in qualitative analysis of mental models interviews to identify differences in expert and lay beliefs as a precursor to developing risk communications (Cox et al., 2003; Thomas et al., 2015). This is the first study we know of to use mental modeling within a grounded approach to access previously un-accessed levels of data in order to have deeper grounding for the development of behavioral theory.

Why electricians work energized, even when they know they should not, then, is the primary research question addressed in this article. We sought to answer it via a workshop with 19 experts, detailed interviews with 60 Ontario electricians to elicit their mental models of influences on risk of injury, and rigorous analysis of resulting data. We suggest that a grounded theory approach that leverages a mental models methodology to make injury event precursors more visible might yield new insights into more general questions as well.

In the next section we discuss theories related to risk taking and safety behaviors in organizations generally and then summarize factors suggested in the literature as relevant to EOI specifically. This is followed by research methods and then empirical findings including an expert model of influences on electricians' electrical safety decision making and behaviors. In the section called "A theory of working energized and risk mitigation implications," we present an integrated theory of electricians working energized, illustrated with a decision tree. This is followed by discussion, limitations, and conclusions, including discussion of how a combined mental models and grounded theory development methodology can help us refine general theories of risk-taking behaviors.

2. Background

We consider five distinct theoretical perspectives on occupational safety/injury: the public health perspective on occupational injury, behavior-based safety, safety culture/climate, the systems approach to socio-technical systems, and a decision theoretic approach.

Most research on occupational injury takes a public health perspective using quantitative methods to assess factors associated with injury rates (Smith, 2001). Factors examined typically relate to the

[1] Arc flash/blast results when electric current travels through the air to another object that offers conduction or grounding potential – including a human body (Picard et al., 2013). This leads to injuries from heat, light, and waves of high air pressure; arc blast can throw workers, causing blunt force trauma, cuts, and abrasions; impulse sound waves can cause temporary or permanent hearing loss. Arc flash/blast is responsible for 2% of fatal EOI and 31% of non-fatal EOI in US construction (McCann et al., 2003).

[2] Though not, as we shall see, all risk; electricians can work energized when they believe they have de-energized. For example, they may have de-energized only to have someone else re-energize circuits without their knowledge. Working near live wires also poses risk of EOI.

[3] Electrical Safety Authority (ESA) is an administrative authority that acts on behalf of the Ontario Provincial Government to monitor and license electrical contractors, and improve electrical safety in the province. ESA funded this research.

injured person (demographics, occupation, training), the context (e.g., industry, type of work being done), and injury cause (e.g., "contact with current of machine, tool, appliance or light fixture"). Often factors examined are those available in government repositories of data employers must report following fatal or serious occupational injuries. This line of research sheds little, if any, light on individuals' behavior and none on their decision making, although it may be that the factors examined reflect influences on decisions and behaviors.

The behavior-based safety perspective has roots in organizational behavior research where the focus is on relationships between goals, intrinsic motivators (e.g., a feeling of work well done), extrinsic motivators (e.g. salary), job design, and propensity to work toward organizational goals (Amabile, 1993; Corgnet et al., 2015; Hackman and Oldham, 1976). Typical change efforts involve detailed analysis of well-defined tasks in specific contexts, introduction of new technologies and methods to change behaviors, setting of performance goals, observation and measurement after a change, and rewards and feedback to reinforce desired behaviors (Choudhry, Fang, & Mohamed, 2007; DeJoy, 2005; Tharaldsen & Haukelid, 2009). This line of research suggests that goals, motivators, workplace context, tasks and job design affect workers' behaviors; studies typically do not examine cognition.

The safety culture and safety climate literatures (Casey et al., 2017; DeJoy, 2005; Hofmann and Stetzer, 1998) are rooted in the broader organizational culture literature which assumes that leaders affect organizational culture which influences employees' values, attitudes and behavior (Schein, 2010, 1996). While many theorists distinguish organizational climate (what people experience in terms of everyday policies, practices, etc.) from organizational culture (values and beliefs about how things are), the two are often not distinguished in the safety literature (Casey et al., 2017). Constructs considered in safety culture/climate research include leader behavior and communications, management style and commitment to safety, safety communications, safety training and activities (e.g., safety meetings, checklists, and feedback), norms and values, and attitudes and beliefs (see also Choudhry et al., 2007). The focus in these research streams typically is on organizational-level constructs that are likely to affect individuals' beliefs, measures of worker attitudes toward safety, and possibly some other belief measures.

Research on large-scale accidents uses a systems approach to understand how complex socio-technical systems impact system-level safety (Holden, 2009). This approach grew out of events around the time of World War II, when engineers realized that in order to reduce aviation accidents it was more efficacious to redesign planes than it was to look for 'better pilots,' as had been the focus. The general idea is that behaviors that lead to large-scale accidents are influenced by and tightly coupled with many social and technical factors and that improving safety requires understanding the entire socio-technical system. Factors examined as influences on safety include workers, their interactions, technologies, processes, human-technology interfaces, leadership, and culture. Application of this approach is usually to complex, high-risk technologies where the greatest concern is disastrous 'normal accidents' (Perrow, 2011), with special focus on leader behavior and culture. The focus is not on contexts where the concern is 'simple accidents' involving one or a few people (Jørgensen, 2016), e.g., EOI.

Applying a decision making under risk and uncertainty perspective is fairly recent in injury prevention literature (Austin and Fischhoff, 2012). Foundational assumptions in this research stream are that behavior is goal oriented, choice is based on perceptions of alternatives and related consequences, risk perceptions can be predictably biased due to cognitive limitations, and experts and non-experts often have important differences in their mental models of a given situation (Baron, 2000; Hastie and Dawes, 2010). People judge a risk situation as acceptable when the risks are well known, controllable, voluntarily engaged in, and not associated with catastrophic loss; situations that are new, unknown, perceived to be out of the person's control, and potentially catastrophic lead to risk avoidance or risk mitigation behavior (Fischhoff et al., 1978). Generally, people tend to be overly optimistic about their abilities (Weinstein and Klein, 1996), and perceive that they can take risks that others like them should avoid (Stone et al., 2013). This paradigm has been applied to many contexts, but seldom in the domain of occupational safety/injury.

2.1. Factors known to be associated with EOI

In reviewing literature specifically on EOI to electric workers, we group findings about influences on safety behavior into four categories suggested by the above research streams. Most published research on EOI to electric workers has been conducted within the public health paradigm and does not examine cognitive or organizational factors. We found only three studies that examined individual and organizational influences on electric worker safety behavior: Tulonen's PhD work was the most comprehensive, considering risk perceptions and context influences on EOI, conducting surveys with 541 Finnish electricians, focus groups with 95 workers, supervisors and others, and observation of electrical work (Tulonen, 2010). Kowalski-Trakofler and Barrett (2007) reviewed 836 narratives of electric arcing incidents in US mines and interviewed 32 vicitims or witnesses to arc flash events (including 23 electricians) to consider the role of safety culture and behavior in EOI. Howe's masters thesis included focus group interviews with 20 Ontario electric workers, including some electricians, to explore why electric workers work energized (Howe, 2011, 2008).

Worker demographics, training, expertise. In the US, 99% of fatal and 81% of non-fatal OEI involve men (Campbell and Dini, 2015; U.S. Department of Health and Human Services, 1998); this may simply reflect male dominated occupations. Some studies show that younger workers have a higher rate of fatal EOI than older workers (Janicak, 2008; Taylor et al., 2002). However, most electric workers suffering EOI are quite experienced (Kowalski-Trakofler and Barrett, 2007; Mäkinen and Mustonen, 2003). Explanations include that experienced electric workers are given more risky tasks (Janicak, 2008) or that they take more risks (Kowalski-Trakofler and Barrett, 2007; Tulonen, 2010). An alternative is simply that most electric workers are relatively experienced, given long careers, and thus we would statistically expect them to have the most injuries. Incident investigations point to insufficient training playing a role in EOI (U.S. Department of Health and Human Services, 1998). Electric workers themselves suggest that knowledge, training, experience, skills, and task familiarity play roles (Howe, 2011; Kowalski-Trakofler and Barrett, 2007; Tulonen, 2010).

Context: Industry/worksite/tasks/technology. In Ontario, 24% of fatal EOI (all occupations) are in commercial settings, 19% in industrial settings, 19% in residential settings, and 5% in institutional settings; 43% of incidents happen during repair/maintenance activities and 29% during construction activities (ESA, 2014). In the US, the extraction and construction industries have the highest fatal EOI rates (Cawley and Homce, 2003; Taylor et al., 2002); construction and manufacturing having the highest non-fatal EOI rates (Gammon et al., 2015). There is very little discernable information about which tasks are associated with higher rates of EOI. For example, twenty-two percent of fatal EOI (all occupations) occur during "installation and maintenance of electrical systems and equipment" (Cawley and Homce, 2003). "Troubleshooting" or "maintenance/repair" were the tasks most frequently associated with arc-flash blast in mining (Kowalski-Trakofler and Barrett, 2007). Zhao et al. (2014) found that 28.6% of fatal EOIs in US construction happened to workers employed by specialty trade contractors who install and operate specialized building equipment, perhaps suggesting that something about such work or job-sites affects risk of EOI. Thirty-one percent took place during residential construction projects; 24% took place during construction of non-residential buildings; over 75% occurred outdoors. Other work and worksite characteristics that affect the chance of EOI include availability of accurate diagrams (Tulonen, 2010), quality of equipment maintenance (Kowalski-Trakofler and Barrett, 2007), current (AC or DC) and voltage

(Fink et al., 2011), equipment worked on (McCann et al., 2003), and availability of needed tools or PPE (Tulonen, 2010).

Other factors at the worksite include time pressures and demands to not disturb power delivery from contractors or customers/clients (Howe, 2011; McCann et al., 2003; Tulonen, 2010), disturbances/distractions (Mäkinen and Mustonen, 2003), poor communication (Kowalski-Trakofler and Barrett, 2007), and unplanned events such as someone turning power back on (Howe, 2011; Tulonen, 2010). Standards such as CSA Z462 Electrical Workplace Safety Standards (Canadian Standards Association, 2012), and communications and policies by regulatory agencies are intended to influence electricians' safety decisions.

Organizational factors found to influence electric worker decisions and behaviors include schedules, supervisor pressures and safety culture (Howe, 2011; Kowalski-Trakofler and Barrett, 2007), practices regarding written safety policies, safety meetings, inspections and training (Campbell and Dini, 2015; Zhao et al., 2014), working alone (Tulonen, 2010) and provision of proper tools (Tulonen 2010). Work paid by the job, focus on financial factors, and amount of work assigned (Tulonen, 2010), peer behavior (Howe, 2011), and work culture that normalizes and encourages risk taking (Stergiou-Kita et al., 2015) are proposed to affect EOI. More EOIs occur in small companies (Holte et al., 2015; Howe, 2011), which might reflect different organizational contexts, or that most electricians work for small companies. For example, in the U.S. nearly two thirds of companies in the construction industry employ fewer than five people (Cawley & Homce, 2008).

Risk perceptions and psycho-socio factors. Attitudes, risk perceptions, risk tolerance, and sub-goals influence electrical worker safety behaviors (Howe, 2011; Kowalski-Trakofler and Barrett, 2007; Tulonen, 2010). Tulonen concluded that key factors leading to unsafe work include hurrying, safety attitudes, and "human failure" - laziness, carelessness, negligence, over-confidence, feeling a job is routine, forgetting. Other errors included mistakenly believing there was no electricity, misplaced trust in someone or something (e.g., diagrams), and lack of communication. Workers mentioned complacency, willingness to take risks, being accustomed to the risks, and over-confidence, including rationalizations they've taken the risks before without experiencing harm influencing unsafe behaviors (Kowalski-Trakofler and Barrett, 2007). Other factors included perceptions it is laborious or difficult to de-energize, especially for tasks that don't take long (Tulonen, 2010). More incidents take place later in a shift, suggesting fatigue or desire to finish (Kowalski-Trakofler and Barrett, 2007). Electricians may not be sufficiently aware of the seriousness of non-fatal electrical injury, failing to seek medical care unless injury is obviously very serious (Rådman et al., 2016; Tkachenko et al., 1999).

Summary. The literature to date reveals important correlations with respect to EOI, suggests a wide range of factors that may be relevant to safety decisions, and is suggestive, especially in the few studies based on interviews or focus groups, of some aspects of reasoning that might lead to electric worker unsafe behavior. We suggest, however, that the application of a mental models approach offers the potential to delve deeply into individual level decision making, and to integrate the findings of prior research into a more complete understanding about the sequences of thought and action that lead to unsafe situations.

3. Materials and methods

To understand why electricians work energized, we followed an inductive approach informed by traditional grounded theory methods (Glaser and Strauss, 1967; Miles and Huberman, 1994; Strauss and Corbin, 1998). Our need to delve deeply into the influences on individual decisions prompted us to combine this with a mental models research approach (Morgan et al., 2002; Wood et al., 2017) that is specifically designed to help reveal people's in-depth underlying beliefs that affect decisions (Johnson-Laird, 1983; Morgan et al., 2002). The method entails first eliciting diverse experts' hypotheses about the topic of interest in order to understand a wide range of expert thinking. This composite set of beliefs is diagrammed as an "expert model", typically in the form of an influence diagram. This illustrates expert hypotheses about all of the factors that are relevant to a topic, including how a change in the value of one factor influences the value of another factor (Howard and Matheson, 2005; Morgan et al., 2002). This approach has distinct similarities to a systems approach to accident prevention in that both consider a 'system' and how human and technical components in that system might influence each other. It differs in that the focus is on individual cognition and decision making within that system, rather than on the tight coupling of humans and technologies where a confluence of many factors leads to a system failure.

The expert model informs development of a semi-structured interview protocol to guide in-depth research interviews with representatives from one or more populations of interest to elicit their "mental models." Thus, "mental model" refers to an individual's complex set of beliefs about a topic, while "expert model" refers to a composite model of expert beliefs (or a composite of experts' mental models). Consistent with grounded theory approaches, the approach specifically encourages the elicitation of factors from individual informants that are not necessarily represented in the expert model.

The expert model serves three purposes. First, its development ensures understanding a broad range of expert beliefs about the domain, addressing a concern that too often studies purporting to use a grounded approach ignore extant literature (Suddaby, 2006). Second, it serves to develop focal points for a semi-structured interview protocol and as a guide to designing more granular, detailed probes and follow up questions. Because the experts who actively participate in development of the expert model typically anticipate many elements of the target populations' perceptions, their expert elicitation is, in effect, a rehearsal of the elicitation with the target population (in this case working electricians). Thus, the follow up questions in an interview protocol are typically better questions: more nuanced and able to get at specific elements within a complex set of beliefs than is usually possible with qualitative research. Consistent with the aims of grounded theory research, the approach includes safeguards to ensure that researchers do not limit the scope of their investigation to a narrow perspective, a goal Suddaby argues is often not attained in grounded theory research, and a goal not relevant to deductive research that tests proposed theories. Finally, the expert model serves as an analytical framework throughout the research project.

Although expert models are comprehensive, they by no means are considered "objective" or necessarily correct, and they are seldom complete. New topics often emerge during mental models interviews and differences between experts and various populations are often revealed in perceived influences on decision making and behavior, or in beliefs about the relationships among the influences. Comparisons are frequently very interesting and productive of insight, especially for the purpose of suggesting areas for deeper inquiry; explanations for behavior; and designing communications and other interventions.

3.1. Stage 1 data gathering: the EOI expert model

A preliminary expert model was derived from a comprehensive literature review[4] (summarized above) and discussions with electrical safety experts at ESA. It included broadly defined influences on electric workers' safety decisions/behaviors. More detailed expert models

[4] Published research on EOI specific to electricians is very rare; thus we turned to literature that explores EOI to electric workers generally (includes other electric workers with less electrical training, such as labourers, maintenance technicians, and HVAC installers) although this is also a limited research area. Studies on power line work was excluded. Primarily EU and North American studies were considered.

noting additional factors and more specific sub-factors and their relationships were also developed. These models were reviewed and refined in a facilitated workshop with 19 Ontario electrical work and safety experts including representatives from a local union, the Ontario College of Trades (provides required classroom education), government agencies and regulators (e.g., ESA and Ministry of Labour), as well as owners of licensed electrical contracting companies, supervisors of electricians, and electricians from companies of various sizes.

At the beginning of the day-long workshop we presented the preliminary expert models. Through a facilitated discussion, process participants added a number of factors and relationships among factors that were not found in the literature. This method allowed us to itemize factors relevant to electric workers' safety decisions within the framework of the expert model (including the decision to work energized), and to identify causal relationships among factors.

3.2. Stage 2 data gathering: eliciting electricians' mental models

Interview Sample. To solicit a diverse pool of electricians to sample from, ESA, the Ontario College of Trades, and an electrical worker union sent e-mail invitations to their constituencies inviting participation in research aimed at better understanding influences on electricians' safe work practices. Respondents who completed an online screening survey were entered into a draw for one of four $250 gift cards to a home improvement retailer. 1576 electricians completed the survey.

We used screening demographics to ensure our interview sample of 60 included members of the broader population, sampling within strata and varying: job title, years of experience, size of organization (< or > = 5 electricians), work sector, work type, supervisory responsibilities, union membership, and geographic location. Table 1 shows how the available sample and interview sample varied across sampling factors. About 3% of Ontario electricians are female; we interviewed four females (6.7%). The sample is not purported to be a representative random sample from the Ontario electrician population, but is chosen to vary across selection criteria suggested as relevant in various literatures. Each interviewee received a $50 honorarium for participation. This sample is relatively large for a mental models study where the norm is 20–30 respondents, but was necessary to allow the possibility of some comparisons between sub-groups.

Interview Protocol. One-on-one phone interviews conducted by experienced mental models research interviewers began with open-ended questions allowing respondents to discuss their typical work at a job site. Discussion then moved to topic areas derived from the expert model: goals at work, tasks they believe are most hazardous, and a number of questions designed to elicit perceptions about how personal, project, and worksite factors affect the chance of fatal or serious electrical injury. The interview included several questions about working energized – when this happens; for what reasons; who decides; kinds of precautions taken; what the electrician has experienced. Several questions asked about electrical safety training, guidelines, and communications. Questions were worded so that supervisors were asked about work they supervise, while non-supervisors were asked about work they perform.

Interviewers prompted respondents to explain their thinking in order to understand not only relevant beliefs, but also the assumptions and experiences behind those. To facilitate this, questions had suggested follow-up prompts for use as needed to encourage expanding upon responses. Interviews lasted 45 min on average and were audio recorded, with awareness, assured confidentiality, and informed consent of respondents to enable transcription and in-depth analysis.

Qualitative Data Analysis. The work of electricians is specialized and technical, presenting a challenge for effective data analysis. Analysts had to be sufficiently oriented and educated in order to develop codes that represent meaningful and nuanced themes of causal relationships within complex mental models. Initially a subset of transcripts was read by two of the authors to identify emerging themes. Working with the transcripts, those initial themes, and referencing factors associated with each node in the expert model, a research analyst highly experienced in mental models research developed an initial set of codes for use in systematically coding all transcripts. Codes represented themes at different levels of focus, from specific concepts which may or may not be in the expert model (e.g., the mention of a specific factor at the worksite, such as confined spaces, a factor not discussed in EOI literature or expert workshop, so not in the expert model), to broader themes that might touch on several nodes in the expert model (e.g., needing to negotiate with customers to achieve a mutually acceptable worksite).

Two additional analysts, also experienced, used the codes to analyze the transcripts. The three analysts initially worked together to develop shared understanding of codes. New codes were generally only identified while reading an initial subset of the transcripts, as is common with this kind of coding (Guest et al., 2006). Once coding seemed stable, and

Table 1
Sampling Frame Factors.

Sample Characteristic	Number Interviewed (Number in Sample)
Electrician Experience	
Apprentice	7 (302)
Journeyman w/ < 10 years since Apprenticeship	16 (476)
Journeyman w/ > 10 years since Apprenticeship	37 (798)
Size of Company	
5 or fewer Electricians in Organization	32 (748)
More than 5 Electricians in Organization	28 (828)
Work Type*	
New Construction	31 (522)
Renovation	28 (309)
Maintenance	37 (518)
Other	9 (227)
Supervisory Responsibilities	
Supervisor	29 (699)
Non-Supervisor	31 (877)
Union Affiliation	
Union	27 (677)
Non-Union	33 (899)
Job designation	
Apprentice	7 (302)
Journeyman without Master Electrician Designation	26 (690)
Journeyman with Master Electrician Designation	27 (584)
Employer Type*	
Licensed Electrical Contractor (LEC)	24 (944)
Electrical Equipment Maintenance Co.	5 (38)
Industrial Facility	8 (85)
Other	13 (275)
Work Field/Area	
Residential	24 (257)
Residential (Apartment/Condo)	7 (75)
Commercial	25 (486)
Industrial	25 (493)
Other	11 (265)
Geography	
Eastern Ontario	12 (252)
Central Ontario	8 (217)
Western Ontario	10 (194)
Northern Ontario	6 (142)
Greater Toronto Area	19 (566)
Other*	5 (205)
Total interviewed (Total in sample)	60 (1576)

* Some provided multiple responses.

to facilitate coding within a complex, technical context, each analyst read a specific sub-set of related questions for all respondents. A custom software program that facilitated application of codes to utterances (words, or more usually phrases, sentences, or more), and automated tabulation of frequencies, was used.

We report the percentage of total participants who mentioned various themes to give a sense for which were mentioned most often in responses. Percentages are rounded to the nearest 5% to avoid suggesting more precision than is possible. We do not intend to suggest that reported frequencies reflect population level beliefs as such inferences would be inappropriate. Reported percentage of those mentioning something represents a lower bound on the percentage in the sample who held a given belief because not all sub-topics were discussed with all respondents due to the semi-structured interview format and because some might not have verbalized a held belief when a topic was discussed. For some topics we note potentially interesting differences between more and less experienced electricians. However, we did not compare mentions of all themes by level of experience or by any other factor, so readers should not assume that there are no differences where differences are not mentioned.

Consistent with grounded theory research, our data analysis was highly iterative with frequent discussion among the authors and analysts. Subsequent passes through the data led to identification of how factors combine to lead electricians to work energized or de-energized. Through an iterative process of analysis and interpretation, we arrived at higher level explanations, always mindful to base these on data. Our analysis revealed that working energized results from a series of events and decisions (sometimes involving multiple actors) decidedly more complex than a simple 'yes-no' decision by the electrician to work energized or not. Consistent with our decision-making frame, we found it useful to summarize emerging explanatory patterns in the form of a decision tree.

4. Findings

4.1. Expert model of influences on electric worker safety decision making

Fig. 1A shows a high level expert model (*"Influences on Electric Workers' Judgments and Decision Making Regarding Electrical Safety"*) based on the literature and expert workshop discussions. Starting in the upper left, ***Other Stakeholder Influences*** depict the highest-level context in which the system is based and includes the goals of employers, customers, various government agencies, and others that act as drivers on the system. These stakeholders influence ***External Technical factors, Project and Worksite influences, Culture and Practices within the Collective Body of Electrical Workers, and Individual Electric Workers' Objectives, Values and Perceptions.*** Shaded nodes depict factors about individual workers' personal characteristics, thinking and behavior, with rectangular nodes denoting decisions to be made. The ***Other Individual's Decisions*** node has a dotted border to reflect that this node essentially duplicates the ***Electric Worker's Decision*** node, but for other individuals; it similarly is influenced by all of the other factors in the model, albeit with appropriate modifications to represent the reality of different trades or professions that might be represented by that node. Nodes to the left are the more technical factors related to systems and processes at the worksite and external regulations, practices and technologies. The ***Project and Worksite Influences*** node is shown with a broken boarder to denote that a sub-model further depicting relevant sub-nodes is shown in Fig. 1B. The ***Outcomes*** node in the lower right depicts the safety outcomes most relevant to electricians, employers, customers, and regulators like ESA. This expert model represents safety decisions for the broader class of electric workers, consistent with the literature review that focused on studies of EOI to electricians and other electric workers.

Two more detailed expert models, an intermediate 'Base' model, and a 'Detailed' model, were shared, discussed, and modified at the expert workshop. These further define the high-level nodes in Fig. 1 by breaking nodes into progressively more detailed nodes and itemizing relevant factors that fall into each node's theme. In those models, stakeholders specific to Ontario are named in appropriate nodes, for example, Ontario College of Trades regulates electrician training in the Province. Because these models are color coded to aid interpretation, they are published as online supplements, rather than in the text of this article.[5]

The expert elicitation yielded additional, in-depth insight into factors, sub-factors and relationships between factors not found in the literature. Workshop participants suggested several additional relationships be illustrated in the models. For example, they suggested that ***Individual Electrical Worker Judgment, Decisions and Behaviors*** be shown to influence other 'upstream' nodes in the model such as ***Project and Worksite Influences,*** because some worksite factors can be influenced by the individual electrician, and their experiences over time may influence them to do so. This added relationship is shown with a dashed arrow. A number of factors added during the workshop were not found in the literature including e.g., 'fitness to work' within ***Individual's Social, Psychological and Physical Factors***, with employers noting they sometimes need to have workers sit out from electrical work when under high stress, for example, after just learning a spouse wishes for a divorce; electrician's pride in their work and impact on reputation (in an ***Electrical Worker Outcomes*** node that is a sub-node within the ***Safety Related Outcomes node***), 'site access control' and 'job site housekeeping' (***Project Factors***), 'monitoring and enforcement' (in a sub-node ***Electrical Safety Codes and Practices*** within ***External Technical Factors***), work refusal (in ***Individual Electrical Worker Judgment, Decisions and Behaviors***), as well as other additions.

4.2. Electricians' mental models of influences on electrical safety decisions

In discussing topics organized around the expert model, Ontario electricians provided a rich set of data regarding their thinking about EOI and safe work behaviors. We first report on Ontario electricians' mental models of influences that affect risk of fatal or serious EOI. We then turn to findings related specifically to working energized. Results are organized by themes that emerged in the data.

4.2.1. Electricians' mental models of influences on injury risk

Electricians are highly cognizant of the dangers of their work and are motivated to get home safely. When asked to describe their goals at work respondents most often volunteered "getting home safely" (85%) and "a job well done" (40%), both intrinsic motivations. Some mentioned money/budget (extrinsic motivation) and a few mentioned one or more of a variety of intrinsic and extrinsic motivations including: keeping to schedule, protecting the public, training apprentices in safety, satisfying customers, protecting reputation, following various safety practices, and getting the right people/equipment for the job. One expressed: "*With the type of job I'm in, you make one mistake, you could potentially not be coming home.*"

Old equipment and low quality materials are key concerns. When discussing how factors at the worksite can affect the likelihood that someone will be seriously injured or killed, most respondents (60%) discussed how older equipment and materials pose increased risk. A variety of risks associated with old components were mentioned, for example: materials degrade (e.g., insulation), wires or contacts become loose, perhaps from vibration over time ("*if the contacts are bad it could potentially explode in your face, especially if it was a used breaker or sub-par component"),* switches may appear to be open but have become welded shut over time, aluminum wiring can become corroded, wires

[5] Two more detailed expert models can be found in the supplemental file found at https://doi.org/10.1016/j.ssci.2020.104826.

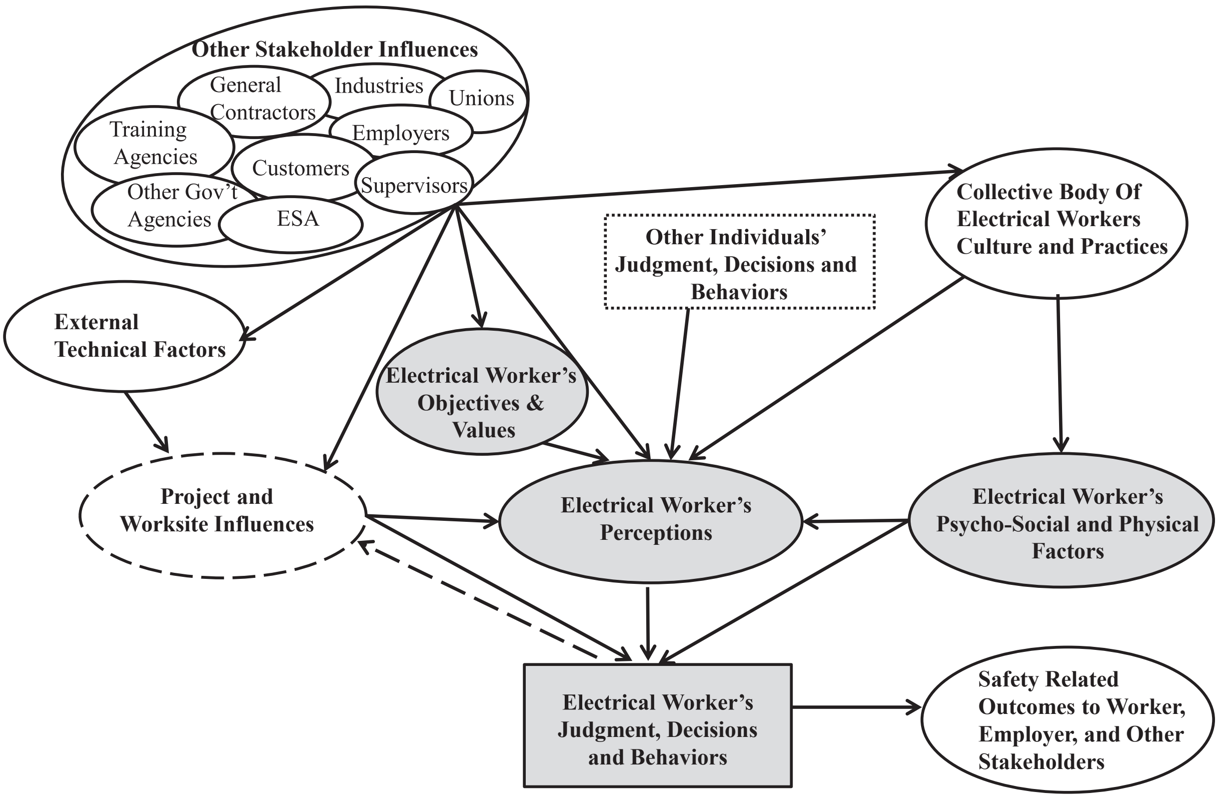

Fig. 1A. Expert Model of Influences on Electrical Workers' Judgment And Safety Decisions* Two more detailed expert models are provided in a supplemental online file.

may be charred due to errors when changing panels and fuses in the past, there can be a mismatch between appropriate and actual voltage being used. Respondents emphasized that preventive maintenance is critical:

"*Whether the equipment has been maintained or not is important. Circuit breakers need to be cycled back and forth. Big huge circuit breakers need to be cleaned and calibrated. You can walk up to an electrical cabinet that has never been cycled for years. It could blow up in your face.*"

Nearly half volunteered that use of low cost/quality materials today increases injury risk now and to future electricians. These respondents

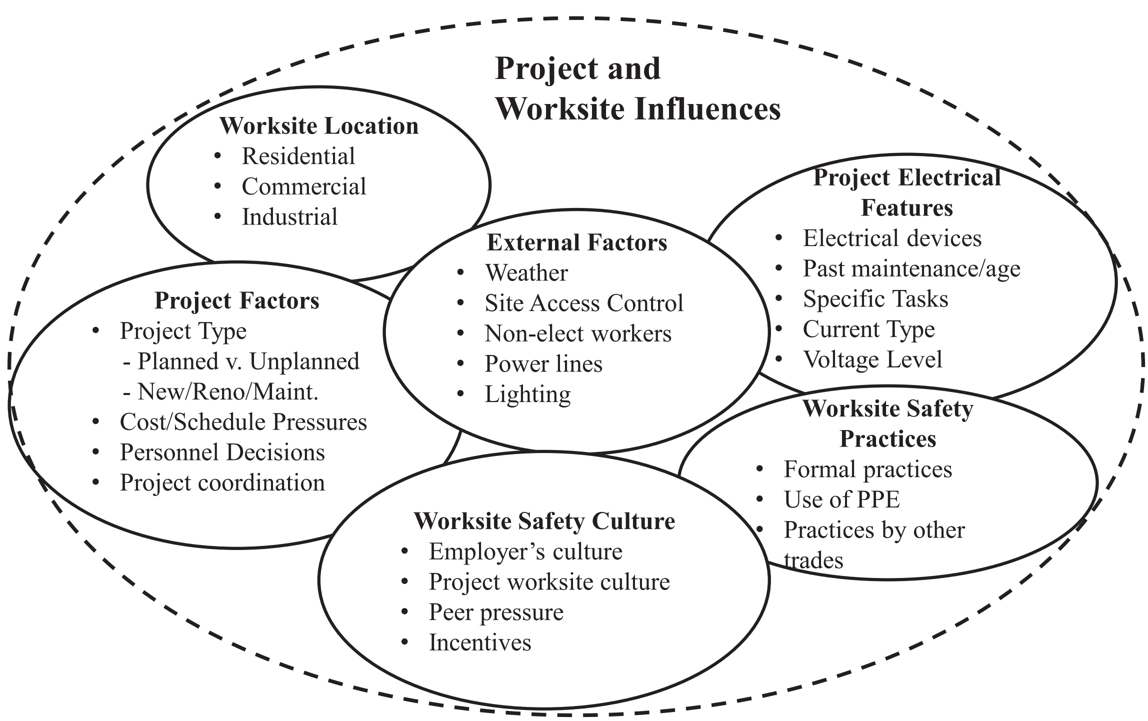

Fig. 1B. Project and Worksite Influences Sub-model.

felt that higher quality parts are more durable and less likely to cause accidents.

Low quality past workmanship presents hidden dangers. About 25% discussed how the quality of workmanship in the past affects injury risk. This concern included that sometimes past work was been done by non-electricians who lack proper training, such as laborers, handymen and homeowners. Concerns included: missing diagrams; drawings that do not match the system; junction boxes not marked with voltages; things are energized that should not be, wiring does not "make sense". Respondents stress that many problems remain hidden from sight. One responded:

"*I think that our primary concern for safety, if that is the question, would be to ensure that the other electricians who worked previous to us left a safe environment so that we can go in, troubleshoot, and move forward. This is so often not the case.*"

Physical and environmental hazards at the worksite increase risk and thus cognitive load. Most (60%) mentioned job site characteristics as influencing risk of injury, for example, presence of hot or dangerous machinery or equipment; hazardous and highly flammable chemicals on site; working on roofs, over beams, on scaffolding, or ladders; working in attics, holes, or other confined areas with limited escape routes; and busy environments at construction sites. About 55% specifically mentioned poor housekeeping, saying that clutter, trip hazards, and wet, dusty, or unclean surfaces affect safety. Nearly as many (45%) discussed increased risk in contexts where access to equipment is difficult. About 25% mentioned weather: hot/cold temperatures, rain, humidity, freezing rain, ice, and wind; some suggested that uncomfortable or risky contexts can make electricians try to work faster:

"In the ice storm last year you couldn't tell if a line was energized or de-energized because freezing rain had frozen all the switches shut. So the fuse could have blown but the switch never opened."
"[In bad weather] instead of going all the way down the ladder to move it four feet over, you make the ladder walk while you are on top of it, just to save a few seconds here and there."

Others at the job site can present safety risks. When discussing the effects of others on safety, about half (50%) discussed risks of working side by side with other trades. They suggested that some other trades don't know or follow electrical safety standards, don't understand their importance, or even ridicule electricians for being 'too safe'. In addition, some other trades may not have the same standards for a clean work site, storage of equipment, or might not accept that power needs to be off. There can be competition for limited space under time pressure. Nearly all (85%) brought up the importance of good communications among all workers on a job site, to point out hazards, reinforce safe work practices, and coordinate work activities to minimize interactions that may adversely impact safety. About 20% noted the end customer can cause distraction at the job site.

About half the respondents (55%) discussed the negative influence of time and budget influences on safety. Several gave examples of times when they "*hurry*" due to pressures that orignate with customers, employers, contractors or supervisors. Another concern is that as deadlines approach, electricians work longer days, leading to fatigue and more injuries. About one in four specifically discussed sometimes feeling pressured to work energized:

"We allow our workers to refuse, but usually we ultimately have to find someone to do it unless we get there and there's a good reason that we can bring to the engineer or the owner and tell them, 'This is why we can't.'"

Electrical work is safer than 10 years ago. Nearly all (80%) said electrical work is safer now than 10 years ago. Some discussed improved procedures and guidelines, stricter safety regulations, and less energized work due to changes that followed ESA's "Don't work live" campaign. Better availability of PPE and better safety equipment is also seen to have improved safety. Some discussed increased focus on arc flash in recent years; about 15% indicated they would like more training on arc flash safety. About 10% felt that things are now less safe than 10 years ago. Concerns included that there are more untrained people such as homeowners doing electrical work and a need for more safety inspectors. A few felt that the focus on working de-energized means that new electricians are not sufficiently prepared when they unexpectedly find themselves working on energized lines or equipment.

4.2.2. Electricians' mental models of working energized

Working energized is perceived to be a high-risk but common behavior. When asked to "think about typical electrical work or tasks that you do (supervise) on a project; which do you think are the most hazardous?" 50% discussed working energized, whether as part of a planned procedure or by accident, 30% mentioned working at heights, and 15% mentioned working on high voltage systems. Further evidence that working energized is common is reflected in the fact that nearly all interviewees with more than 10 years of experience (90%), and most with less than 10 years of experience (60%) discussed experiences with working energized. 20% volunteered that they never intentionally work energized, a often attributing this to company policy or to being an apprentice who is not allowed to work energized.

Usually the choice to work energized reflects perceptions doing so is necessary, although convenience is sometimes a factor. Respondents said they assess the particular situation, level of risk, availability of PPE, and the safety of nearby others when deciding whether to work energized. Respondents with 10+ years of experience were more likely than those with less experience to report that they themselves decide whether to work energized (50% versus 20%). These results may simply reflect that electricians are first apprentice, then licensed journeymen, then licensed master electricians who can supervise others. When discussing who else makes the decision, supervisors, foremen, and general foremen were mentioned although some suggest the customer decides:

"I guess the customer or the engineer, and they say they can't have a shut down. Everything's too important that they can't shut it down, so you're going to have to work live."

About 20–25% in each experience-level group volunteered that some tasks/situations dictate working energized, meaning there is no decision to be made. When asked what tasks "have to be worked on in an energized state?" most informants with more than 10 years' experience (60%) and some (30%) with less than 10 years' experience discussed troubleshooting or testing. About 25% talked about environments where computer data or safety, e.g., in hospitals or on roadways, would be compromised. Working on panels was also mentioned somewhat frequently, by 15% overall.

"You're allowed to work live when you are troubleshooting. You have to wear the proper PPE, face shields, gloves and all that. We do work live when we are troubleshooting because you can't work on dead equipment when you troubleshooting. So I do work live."

A theme in a few responses was that working energized is sometimes done for convienience:

"You have to get something done and it would cause you more headaches, or it would be more inconvenient to do it if you had to turn the power off."

Overt pressure to work energized can lead to working energized, negotiating to safer conditions, or work refusal. While about 55% said they do not feel such pressure, as noted above, about 25% mentioned that they do. Only one respondent reported he would be unable to refuse a request to work energized; others said they could refuse such work and generally said they would be comfortable doing so. About 20% of respondents suggested they often agree to work energized when asked. Some with more than 10 years of experience described how they felt pressure to work energized in the past but no longer do. A few noted this was due to a change in attitudes; some suggested that their age or experience affords a better position to refuse:

"They put a lot of pressure to keep the lines going. With my years of service, I get pretty comfortable and nobody seems to push. With my experience I just don't do it anymore."

As an earlier quote suggests, electricians feel they need a 'good reason' to refuse working energized, or they believe someone else will end up doing so if that is what the customer/client/contractor demands. Some discussed having to negotiate and work around requests to work energized, for example by getting agreement to do the work at night to avoid things like shutting down needed office computers or restaurant kitchens. This can introduce new risks, for example bad lighting or fatigue.

"The production guys do pressure you because they don't want to shut down production. But if we can't shut it down, we don't do it. So if it needs to be shut down at 2 a.m. Sunday morning or something, we'll actually plan to schedule that, to go in and do it at that point."

Negotiating to safe work outcomes was not an issue identified in previous literature on EOI. Electricians do not necessarily find it easy to convince their customers:

"It's kind of hard to get the customer to understand the safety involved in turning it off and shutting down the whole plant just to do a little bit of work for something that small."

Ontario electricians work energized less often than they used to. A common theme in interviews was that Ontario electricians work energized less than they used to. Some referred to a change in culture within the collective body of Ontario electricians around the appropriateness of working energized, with working energized no longer seen as "being a man". Several mentioned that ESA's "Don't work live" campaign had reduced working on energized equiment or wires, with one explaining it had been taken up by the unions and then by employers, leading more and more electricians to decide "it's not worth it." In Ontario, most safety training for apprentice electricians occurs on-the-job during apprenticeship, rather than in formal classroom training. A few were concerned that the move away from working energized has led to a point where apprentices no longer receive sufficient on-the-job training working energized, leaving them at greater risk of injury when they do encounter it:

"There's so much de-energization talk and awareness these days that if I have new apprentices coming up that never worked on live work, there may be a time when they have to. They may do it and even think they feel comfortable doing it, and that's when things happen because they're not trained to do it as much nowadays, especially on lower-voltage systems."

Working energized sometimes happens unexpectedly. Nearly half (45%) discussed times they believed that they were working de-energized but discovered they were actually working energized. Respondents discussed what led to such misunderstandings, including: others who wrongly said that something was de-energized; other electricians, workers or homeowners turning energy on; someone de-energizing the wrong thing; multiple sources of power; insufficient markings/missing diagrams; poor quality work done in the past by other electricians or by un-trained homeowners or handymen; not taking actions to prevent others from turning power on. Several suggested such events were a learning experience:

"I was supposed to be working on a de-energized box in a ceiling 25 feet up. I went to take the cover off of it. A bunch of wires sprung out. There were 600 volts grounded against a pipe run located in the ceiling, which attached itself to the T-bar, which attached itself to me. I got electrocuted under 600 volts. I woke up about 45 minutes later suspended half off the scaffold."

"My boss said, 'Yeah, it's dead.' I went to grab it and it's 220 volts. So my muscle tensed up. I was very lucky and let go of it. I think I was 18 or 19, and from that day on I don't trust anybody. I always go check myself."

While aware of the risks they face, many do not do hazard assessments. When discussing how they decide whether to work energized or not, respondents said they consider the particular situation and the risk it poses, availability of PPE, and who is in the area that might come into contact with whatever is being worked on. A standard followup question for electricians who reported sometimes working energized was whether they or their team do formal hazard assessments. Although just over half (55%) said they have conducted formal hazard assessments, perceptions of "formal" varied from five minute talks at the start of the day, to written assessments and checklists mandated by their companies, to laying out all of the steps that must be done to complete the job. About 25% of all respondents reported not doing any kind of hazard assessment, formal or informal, before starting a job. These behaviours are at odds with electrical work safety standards. Since not all respondents were asked this question the percentage in our sample who do not do such assessments could be higher.

Respondents were asked about safety steps they take when working, whether energized or de-energized. Responses were coded as shown in Fig. 2. Using PPE was the safety step mentioned most frequently, for example use of rubber mats, flame retardent clothing, face shields or glasses. One mentioned having a motion sensing device that can signal to the home-office that an electrician who is working alone has not moved for some specified time, suggesting an injury, and sending

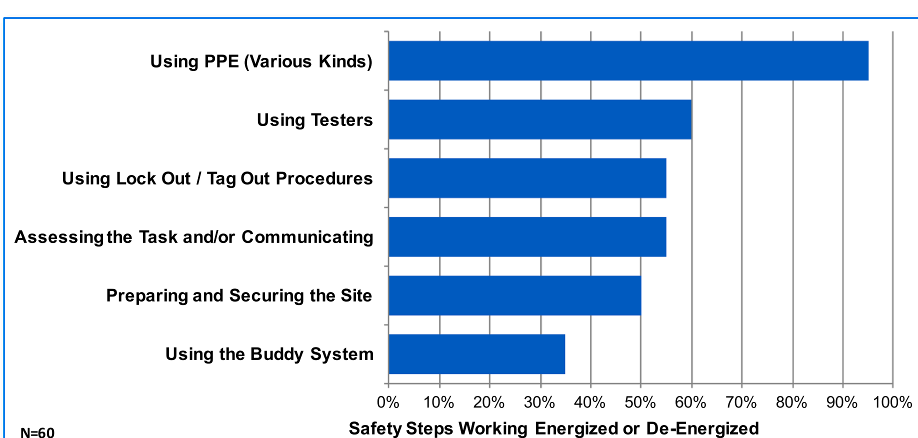

Fig. 2. Reported safety steps when working.

location information so help can be sent. These findings should be considered with respect to safety standards which identify use of PPE as less effective than steps that eliminate risk (e.g., de-energizing the system).

Over half mentioned using testers as a safety step, with a few noting the importance of testing the tester before de-energizing, to ensure it is working. Both lock-out/tag-out actions and actions related to assessing the task at hand were also mentioned by about half of respondents. About 30% mentioned that they always work with a second person, a key safety precaution should one electrician be shocked and unable to let go of wires. Some respondents discussed that they take fewer precautions when working de-energized; for example, about 25% mentioned they use less PPE in such situations.

4.2.3. Summary of findings related to working energized

Electricians are cognizant of electrical work risks and are likely to see working energized as the most dangerous thing they do, even though choosing to work energized is less frequent than it used to be. The most frequently mentioned reason for choosing to work energized is belief that certain tasks or contexts require energy, followed by pressures from others to keep power, on. Convenience or saving time can also affect this choice. Other times, electricians find themself *unknowingly* working energized due to chance events following an attempt to de-energize. For example, they may not have de-energized when they thought they had due to lack of skill or missing information, or others might turn on energy without their knowledge. Even though they recognize the hazards of their work, and many have been surprised by unexpected energy, a good number report not doing any kind of hazard assessment when starting a job, and among those who do, what constitutes a hazard assessment varies considerably.

5. A theory of working energized and risk mitigation implications

The "Working Energized Decision Tree" (Fig. 3) depicts key decisions and chance events distilled from this research. Rectangular nodes depict electricians' decisions; the focal decision is whether to work energized. Small black circles allow for multiple instantiations of a given choice. Larger circular nodes represent chance events. These might reflect the electrician's actions or others' current or past actions (e.g., improper wiring in the past). Outcomes include knowingly working energized, unknowingly working energized, and working de-energized, depicted by diamond shaped nodes. Unsafe outcomes that we wish to see eliminated from the tree are outlined with a broken boarder.

The focal decision, *Whether to Work Energized* is influenced the *electrician's mental model and the influences on decisions in the specific context*, represented by the oval node in the lower left.[6] This includes the electrician's beliefs about whether the task at hand must be done energized and requests to do so. This decision is also influenced by the *Hazard Assessment* decision and what is learned as a result; these are connected with a dotted arrow to illustrate the concern that many electricians may not conduct hazard assessments.

If the electrician chooses to work energized three outcomes are possible, depending on why 'Yes' is chosen:

- *Appropriately Work Energized* results when the electrician appropriately determines the task fits the limited criteria for working energized. Risk mitigation involves stakeholders ensuring availability and use of PPE and other safe work practices, including use of hazard assessments.
- *Knowingly Work Energized Due to Incorrect Beliefs* results from incorrect belief that a task fits criteria for working energized. Training is needed to address common knowledge gaps or misperceptions; further work is needed to assess what these are, including to assess accuracy of perceptions about the need for energy when testing and trouble shooting.
- *Works Energized Knowing it is Not Appropriate* results when de-energizing is advised, the electrician knows that, but chooses to work

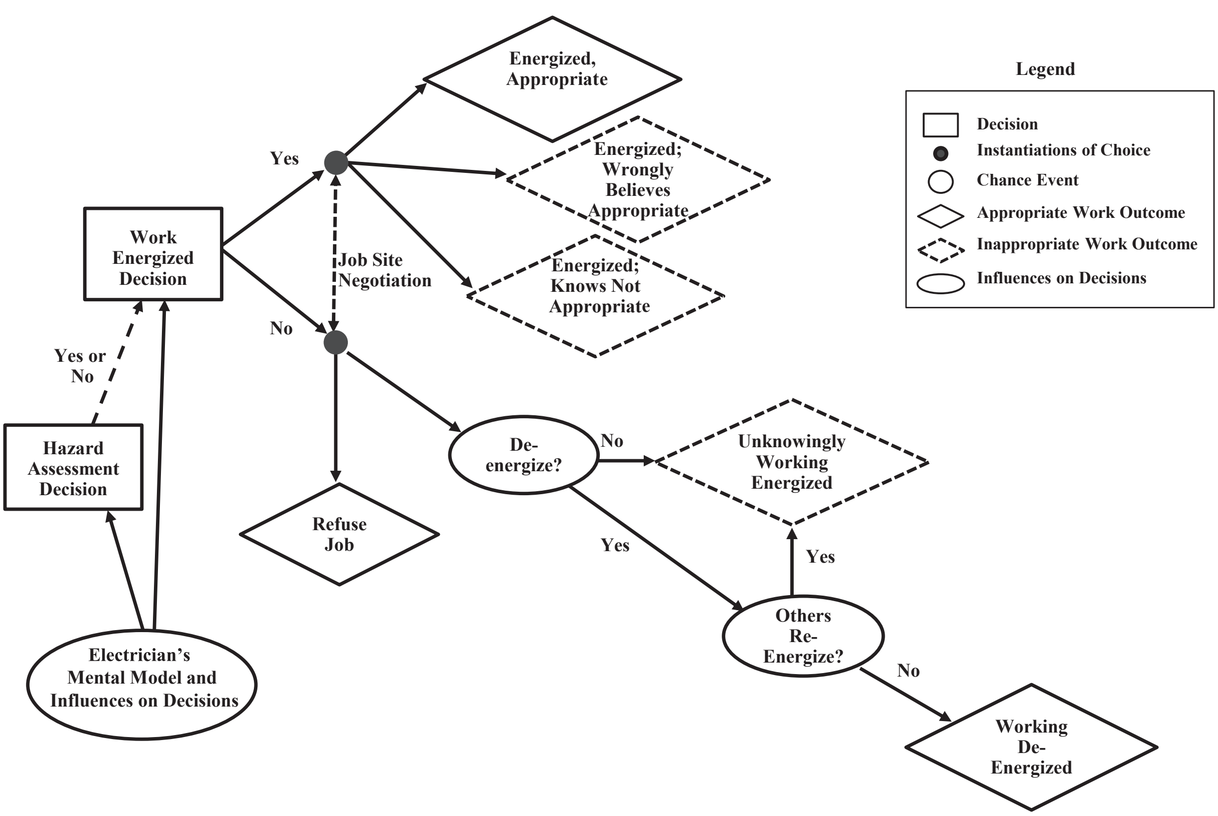

Fig. 3. Working Energized Decision Tree.

energized none-the-less. Influences include pressures from others, convenience, deadlines, etc. Employers, educators, unions, and regulators can reduce this risk through training and interventions to change incentives, safety culture/climate and norms that lead or pressure electricians to make poor choices. Education is also needed for employers/supervisors/customers/contractors who might underestimate the dangers associated with requests for energized work.

If the electrician determines he/she should *not* work energized, three things might happen:

- The electrician can directly proceed to De-energize; or
- If asked to work energized, the electrician can *Refuse to do the Job*; or he/she can
- *Negotiate* to Working De-energized, depicted by a dotted arrow connecting 'yes' and 'no,' to indicate the possibility of changing between these. Deciding to work energized in this case branches to *Working Energized When Knows Not Appropriate*. Successful negotiation to 'no,' which might entail a compromise such as working at night, branches to the *Power Off* chance node. Electricians may need training and tools to aid in negotiating, something that to the best of our knowledge is not standard training, in order to prevent this risk.

De-energizing is shown as a chance node because the effort may or may not be successful. If not, the electrician will *unknowingly work energized.* Respondents reported many factors that influence their ability to assess what is required to de-energize: quality, age, type and complexity of the system; availability of diagrams; quality of past electrical work; physical barriers and constraints that limit what can be seen. An electrician might do everything right given available information and still not successfully de-energize because of things that cannot be seen or known. Skill is also relevant to avoiding this outcome. Training and safe work practices, including proper hazard assessments and documentation, are the best defenses against this risk. All relevant stakeholders should emphasize the importance of these practices and work to create incentives, work practices and a broader culture where these are the norm.

If de-energizing is successful there is a chance others might re-energize, represented by the node *Others Re-energize.* Respondents recounted times this happened accidently, or with intent. Because interviews focused on working energized, lockout/tagout - meaning procedures to lock others out of a system so that they cannot turn energy on - was only sporadically discussed. We implicitly assume lockout/tagout is part of de-energizing, noting this important safety pre-caution needs further study.

The decision tree shows that safely working de-energized does not simply follow from choosing one of two *alternatives* (work energized or not), as had been implicitly assumed in ESA's "Don't Work Live" campaign. Instead, for an electrician to arrive at the *outcome* of safely working de-energized requires: 1) accurate knowledge of the situation, informed by a hazard assessment; 2) accurate knowledge of when it is appropriate to work energized, 3) avoiding temptation to work energized due to convenience, 4) the ability to either walk away or negotiate to safe working conditions, 5) the requisite skills, information, and tools to properly de-energize, and 6) for others to not intentionally or unintentionally re-energize the system. This is a considerably more complex decision tree than was assumed at the start of this research.

[6] Interview data suggest an electrician's supervisor may make decisions about hazard assessments and working energized. For simplicity, we refer to the electrician making these decisions.

6. Discussion

One might think of electricians as specialists who arrive in ones or twos to complete a specific task, executing their expertise in isolation from the context they are working in. The expert elicitation and interview data revealed that in fact, electricians' in-the-moment safety decisions may be simultaneously influenced by many factors found in the expert model. These include specifics of the task at hand (*Project Factors*), status of equipment to be worked on (*Project Electrical Features),* safety practices such as conducting a hazard assessment (*Worksite Safety Practices*), cost and schedule pressures (*Project Factors*); the *Electrician's Objectives, External Factors* such as weather, beliefs of whether tasks require energy (*Perceptions*); employer rules (*Employer Safety Culture*); requests, incentives and pressure from customers or general contractors and behavior of others at the site (*Project Factors and Other Stakeholder Influences*), as well as training and norms (*Collective Body of Electrical Workers Culture and Practices*). Having decided to de-energize, the electrician's ability to do so is affected by *Perceptions*, training (*Collective Body*), experience (*Psycho-Social*), and many *Worksite Factors,* as well as by *Decisions and Behaviors of Others* in the present or the past. From this we see the complexity of these seemingly simple decisions and the physical and cognitive demands electricians routinely work under. Perhaps this helps explain why others, not comprehending the complexity of electricians' work, request that energy remain on, on top of everything else the electrician must manage.

Two additional contributions to the literature that result from this study are that Ontario electricians consider work by untrained homeowners or handymen to present risk to electricians who come later, and that many seem to omit hazard assessments. More work is needed to understand how common these actually are and the decision making behind these unsafe practices.

We see from this study the inherent difficulties in identifying how to prevent occupational injury based on studies that do not explicitly consider influences on decision making and behavior or that take a narrow theoretical perspective and limit study to a pre-defined subset of factors. For example, studies finding that most electrical injuries occur to more or less experienced workers or when working on "installation and maintenance of electrical systems and equipment," as studies using a public health perspective have found, give no insight into interventions to reduce injury risk. On the other hand, knowing which safety practices are most likely to be ignored (e.g., hazard assessments), or that certain specific tasks are seen to require working energized when they do not can inform design of risk prevention interventions.

A critical assumption in this research was that choosing to work de-energized removes most of the risk of EOI, leading to significant focus on why and how electricians work energized. Our results show that changing electric workers' decisions about working energized from 'yes,' to 'no' requires addressing erroneous beliefs about when to work energized and instilling norms to omit energized work that is not necessary. We need to reduce requests to work energized and help electricians be better able to refuse such requests. However, these efforts cannot address the two paths in the tree that lead to *unknowingly* working energized. Our interview data does not tell us whether most energized work is by choice or is unknowingly encountered, but many electricians have experience the latter, and it logically presents more risk. The decision tree in Fig. 3 can guide systematic coding of fatal, serious, and near-miss EOI incidents to determine which path in the tree led to each incident. Such analysis would help researchers and practitioners assess common root causes of injury and help prioritize risk reduction efforts.

In fact, since this study ESA has started examining "lack of hazard assessment" as a probable cause of occupational electrical fatalities. Analysis shows that lack of hazard assessment was a probable cause in 26% of electrical occupational fatalities in Ontario during 2006–15 (ESA, 2016), 20% in 2007–16 (ESA, 2017), and 19% during 2008–2017

(Electrical Safety Authority, 2018). Our work, together with this data, suggests a need for regulators, like ESA, and other key stakeholders including unions and employers, to work together to support and enable continuous learning and sharing of best practices through establishment of a Community of Practice that focuses on improving safety decisions and behaviors, including routine conduct of hazard assessments.

Another interesting contribution to the literature is the finding that electricians sometimes must negotiate to safe working conditions. This was not discussed in great detail by respondents, nor did most respondents indicate how they feel about their skill in this area, suggesting need for further study – how often does this happen? what are the aids and barriers to successful negotiation? We do not believe that negotiating to safety is a standard part of formal or apprenticeship training in Ontario and are not aware of literature on this topic. This research suggests the need for such training, and also for aids or standard practices that help electricians achieve agreement to de-energize.

This work demonstrates that a grounded theory approach can leverage a mental models methodology to make the precursors to undesirable behaviors in organizations more visible. Pre-cursors influencing unsafe decisions/behaviors include individuals' mental models, organizational influences, other stakeholders and external influences, the system being worked on, and the specific work context. This research provides an example of how the two research methods are complementary, and together offer more than either alone. The approach used allowed us to go deeper than simply 'blaming the individual' in seeking causes of unsafe behavior in organizations. In considering the decision tree and thinking about interventions to prevent unsafe behaviors, we easily see that the typical remedies calling for better training only address the cognitive precursors. Addressing the other pre-cursors requires focus on organizational changes to incentives, management, or safety culture, or changes to external influences outside the organization, that affect not only the focal actor, but those who influence his or her decisions and chance events that affect paths followed.

7. Conclusions

The mental models interview data provided insights not found previously in other published studies related to electrical occupational safety and injury. This method, when combined with the grounded theory approach to theory development, was especially powerful in helping make visible why undesired behavioral outcomes arise. We believe the advantages it offers, in terms of allowing an in-depth understanding of multi-faceted complex behaviors and outcome states, establish its value as a research approach. We believe this is an approach that could be fruitfully employed to understand a wide range of decisions and behaviors, not only within occupational injury, but regarding other types of unsafe behavior in organizations as well.

Our study is not, of course, without limitations. The small sample size and qualitative analysis limit generalizability to broader populations, although this work provides rich insights that can be used in designing quantitative research to understand population level beliefs, behaviors, and experiences. It is possible our small sample is biased towards electricians who are especially concerned about electrical safety, or in some other way, despite our efforts to avoid building bias into our sample. The sourcing of our data in Ontario might make some findings less relevant to other geographies.

Electricians' safe work decisions take place in complex, dynamic settings. Incident reports that stop at determining a worker did something wrong seldom elicit the rich detail found in the qualitative data analyzed in this study. This work demonstrates how a decision theoretic systems approach, very different from the public health approach that permeates most occupational injury prevention literature, and from the behavioral safety or cultural safety approaches that permeate most organizational safety literature, has great potential to help us understand the complex social, technical, and context factors that influence individuals' decisions and safety behaviors, which in turn affect the probability and magnitude of injury.

8. Author notes

This work was supported by the Electrical Safety Authority, Ontario. The work and conclusions are those of the authors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssci.2020.104826.

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