ASSESSMENT OF COVID-19 BARRIER EFFECTIVENESS USING PROCESS SAFETY TECHNIQUES

by

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Dalhousie University is located in Mi'kma'ki,
the ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

Dedicated to

All the frontline workers of the COVID-19 pandemic.

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Abstract

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causes a respiratory illness called the novel coronavirus 2019 (COVID-19). COVID-19 was declared a pandemic on March 11, 2020.

Bow tie analysis (BTA) was applied to analyze the hazard of SARS-CoV-2 for three receptor groups: patient or family member at the IWK Health Centre in acute care, staff member at a British Columbia Forest Safety Council (BCFSC) wood pellet facility, and staff member at the Suncor refinery in Sarnia, Ontario. An inherently safer design (ISD) protocol for process hazard analysis (PHA) was used as a guide for evaluating COVID-19 barriers, and additional COVID-19 controls were recommended. Furthermore, two communication tools were developed from the IWK bow tie diagram to disseminate the research findings.

This research provides lessons learned about the barriers implemented to protect people from contracting COVID-19 and their corresponding degradation factors and degradation factor controls, and about the use of bow tie diagrams as communication tools. This research has also developed additional example-based guidance that can be used for the COVID-19 pandemic or future respiratory illness pandemics. Recommended future work is the application of BTA to additional industries, the consideration of ISD principles in other control types in the hierarchy of controls (HOC), and further consideration of human behaviour and human and organizational factors (HOF) in BTA.

List of Abbreviations Used

ADE	Adverse Drug Effect
AIIR	Airborne Infection Isolation Room
BASES	Bluewater Association for Safety, Environment, and Sustainability
BC	British Columbia
BCCDC	British Columbia Centre for Disease Control
BCFSC	British Columbia Forest Safety Council
BTA	Bow Tie Analysis
CAER	Sarnia-Lambton Community Awareness and Emergency Response
CCOHS	Canadian Centre for Occupational Health and Safety
CCPS	Center For Chemical Process Safety
CDC	Centres for Disease Control and Prevention
COVID-19	Novel Coronavirus 2019
CPI	Chemical Process Industry
CVC	Central Venous Catheterization
EI/CCPS	Energy Institute/Centre for Chemical Process Safety
EVS	Environmental Services
FLRA	Field Level Risk Assessment
HAS	Health and Safety Association
HOC	Hierarchy of Controls
HOF	Human and Organizational Factors
HVAC	Heating, Ventilation, and Air Conditioning
ICU	Intensive Care Unit

IEC	Sarnia-Lambton Industrial Educational Cooperative
IOGP	International Association of Oil & Gas Producers
IPAC	Infection Prevention and Control
ISD	Inherently Safer Design
NMM	Non-Medical Masks
NS	Nova Scotia
NSERC	Natural Sciences and Engineering Research Council of Canada
NSHA	Nova Scotia Health Authority
NSNU	Nova Scotia Nurses' Union
OHSW	Occupational Health, Safety, & Wellness
PCR	Polymerase Chain Reaction
PHA	Process Hazard Analysis
PHAC	Public Health Agency of Canada
PPE	Personal Protective Equipment
PSM	Process Safety Management
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
SHEA	Society for Healthcare Epidemiology of America
SLEA	Sarnia-Lambton Environmental Association
UPP	Universal Pandemic Protections
WHO	World Health Organization
WPAC	Wood Pellet Association of Canada

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Thank you to my parents, Kim and Glenn, and to my sister, Emily, for their continued support and for welcoming me back home during these unprecedented times.

Chapter 1 Introduction

This chapter, based on (Turner et al., 2021) with relevant excerpts, provides an overview of the COVID-19 pandemic, the scope of work, motivation, and objectives of this research, and an introduction to the hierarchy of controls (HOC), bow tie diagrams, and the inherently safer design (ISD) protocol for process hazard analysis (PHA). The industrial involvement in this research and the organization of this thesis document are also described.

1.1 COVID-19 Pandemic

The novel coronavirus 2019 (COVID-19) is a respiratory illness caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Burak et al., 2021). SARS-CoV-2 was identified in December 2019. Common symptoms of COVID-19 include cough, congestion or runny nose, diarrhea, fever or chills, headache, muscle or body aches, nausea or vomiting, new fatigue, new loss of taste or smell, shortness of breath or difficulty breathing, and sore throat. While some people with COVID-19 experience no symptoms or have mild illness, severe cases can lead to respiratory failure, long-lasting damage to the lungs and heart, nervous system problems, kidney failure, and death (Sauer, n.d.).

The first case of COVID-19 in Canada was confirmed on January 25, 2020 (Burak et al., 2021). On January 28, 2020, The COVID-19 outbreak was declared a public health emergency of international concern by the World Health Organization (WHO). This label indicated that COVID-19 was an "extraordinary event that constitute[s] a public health risk to other States through the international spread of disease" (Ducharme, 2020a). On March 11, 2020, WHO declared COVID-19 a pandemic; at this time, there were over 118,000

cases in over 110 countries and territories, and sustained risk of continued global spread (Ducharme, 2020b). There have been several COVID-19 variants due to significant mutations of the SARS-CoV-2 virus. As of February 2022, the following variants, considered to be variants of concern, have been detected in Canada: Alpha (B.1.1.7), Beta (B.1.351), Gamma (P.1), Delta (B.1.617), and Omicron (B.1.1.529). Evidence has demonstrated that these variants are more transmissible than the original virus, and/or have an impact on the effectiveness of COVID-19 vaccines (Government of Canada, 2022). SARS-CoV-2 is the hazard of global concern with respect to this pandemic (Rayner Brown, VanBerkel, et al., 2021).

WHO Director-General Dr. Tedros Adhanom Ghebreyesus said, "This is not just a public health crisis, it is a crisis that will touch every sector" (Ducharme, 2020b). The pandemic has disrupted supply chains and business operations across all industrial sectors. In the spring 2021 months, more than twenty outbreaks occurred at oilsands worksites and camps in Alberta, Canada, and the two largest outbreaks resulted in nearly 3,000 cases of COVID-19 (Yourex-West, 2021).

The risk of acquiring COVID-19 continues to drive unprecedented measures worldwide to prevent contact with SARS-CoV-2, and to protect against the potentially severe consequences of illness. To design an effective pandemic risk reduction strategy, the risk posed by the SARS-CoV-2 must be identified and analyzed. Additionally, effective communication of public health measures from decision-makers and public experts is a critical component of a pandemic response (Rayner Brown, VanBerkel, et al., 2021). For example, inconsistent public health guidelines and recommendations of using face masks

to prevent the spread of COVID-19 have resulted in confusion and stigmatization toward wearing masks during the pandemic (Tso & Cowling, 2020).

1.2 Scope of Work

The scope of this research is the COVID-19 pandemic, with an emphasis on the province of Nova Scotia (NS), Canada, and the risk of individuals acquiring the SARS-CoV-2 virus.

1.3 Motivation

The current research was motivated by the need for comprehensive hazard analysis of the unique threat of COVID-19 and effective communication of risk reduction measures during a pandemic.

1.4 Objectives

The first objectives of this research were to identify virus threats and likelihood of infection, and to evaluate current prevention and mitigation measures using a process hazard analysis (PHA) technique known as bow tie analysis (BTA). Another research objective was to explore additional measures based on inherently safer design (ISD) and the hierarchy of controls (HOC). The final research objectives were to efficiently communicate the project findings and to provide guidance for making risk-based decisions regarding the selection of the most effective COVID-19 safety measures.

1.5 Hierarchy of Controls

The hierarchy of controls (HOC) describes the preferred order of consideration for risk reduction measures. From most to least effective, this order is: inherently safer design (ISD), passive engineered safety, active engineered safety, and administrative safety (Kletz

& Amyotte, 2010). Figure 1-1 illustrates the HOC as it is understood in the context of process safety management (PSM).

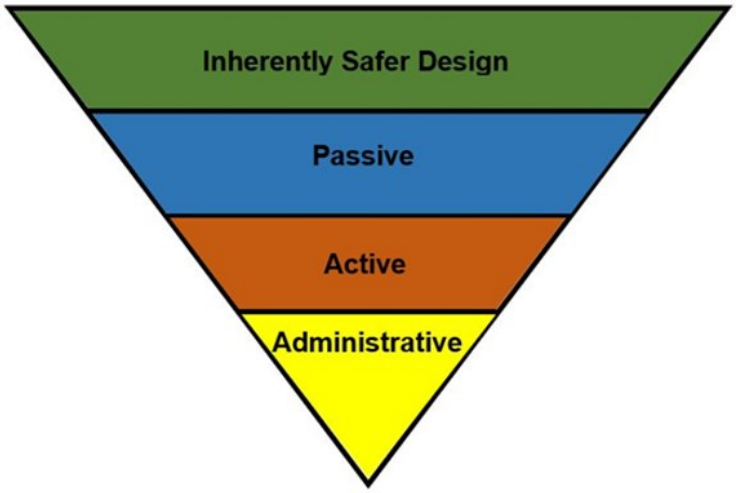

Figure 1-1. The hierarchy of controls as understood in the context of PSM

ISD controls aim to eliminate or reduce the hazards associated with a set of conditions using four main principles: minimization, substitution, moderation, and simplification. Minimization (sometimes referred to as intensification) involves reducing the quantity of hazardous material contained in a process or plant. Substitution involves replacing the hazardous material or process with an alternative that is less hazardous. Moderation involves the use of less hazardous or less energetic process conditions and is largely composed of attenuation and limitation of effects. Simplification involves reducing or eliminating unnecessary complexities and includes the concept of error tolerance (CCPS, 2020).

Add-on safety devices are categorized as engineered controls (Kletz & Amyotte, 2010). Passive engineered safety controls do not require initiation beyond the undesired event

itself. Active engineered safety controls depend on hazard detection, initiation, and support systems. Procedural safeguards are categorized as administrative controls (CCPS, 2020).

It must be noted that ISD, engineered safety, and administrative safety work in cooperation to reduce risk; ISD is not a stand-alone concept. Also, the importance of engineered and administrative safety is not invalidated by the HOC; the risk assessment process must incorporate consideration of all control measures (Kletz & Amyotte, 2010).

According to Rayner Brown, VanBerkel, et al. (2021), incorporating the ISD principles with an ISD mindset may improve other types of controls in the HOC. For example, with respect to the COVID-19 pandemic, maintaining physical distance of 2 m when outside the home has characteristics of the ISD principle of moderation in the form of limitation of effects; maintaining 2 m of distance reduces the likelihood of transmitting the virus to someone else or contracting the virus from an infected individual. However, this barrier is implemented by administrative means and is easily defeated if individuals do not comply. In the context of this research, in addition to the controls as described by the HOC, administrative barriers and controls with characteristics of ISD principles are considered and they are categorized as "administrative (with aspects of ISD)". This distinction aims to highlight the incorporation of the ISD principles while clearly stating that the controls are administrative safety.

Within the context of the COVID-19 pandemic, the HOC has been referred to in several resources. In May 2020, a "hierarchy of controls… for reducing transmission hazards" was presented by health officials in British Columbia (BC), Canada. As illustrated in Figure 1-2, this hierarchy presents the following controls, in order of most to least effective: physical distancing, engineered safety, administrative safety, personal protective equipment (PPE)

(McElroy, 2020). Similarly, Johns Hopkins University in Baltimore, MD used a "modified hierarchy of controls" to represent their COVID-19 mitigation measures (Johns Hopkins University, 2020).

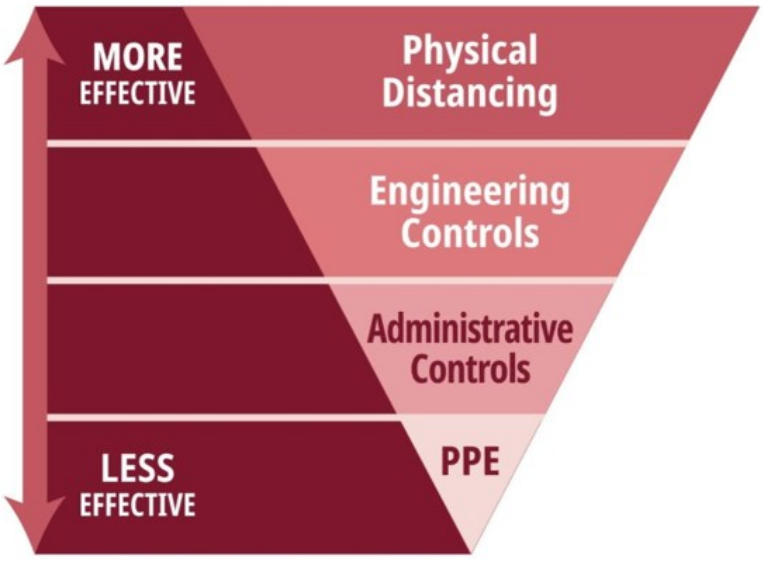

Figure 1-2. The hierarchy of controls as presented by BC health officials (McElroy, 2020)

The HOC was also used by the Canadian Centre for Occupational Health and Safety (CCOHS) to categorize COVID-19 safety measures for workplaces. As illustrated in Figure 1-3, this hierarchy presents the following controls, in order of most to least effective: elimination, substitution, engineered safety, administrative safety, and PPE and non-medical masks (NMM) (CCOHS, 2020).

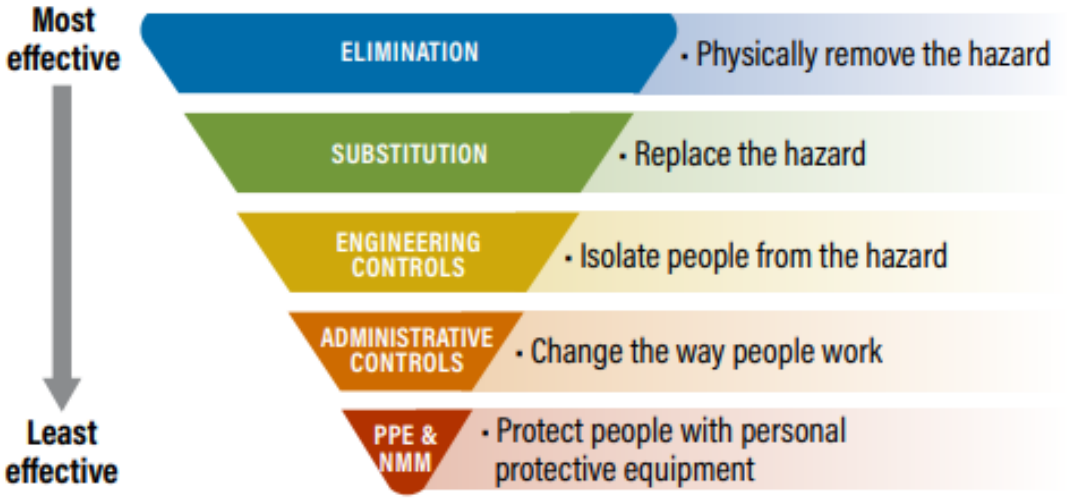

Figure 1-3. The hierarchy of controls as presented by CCOHS (CCOHS, 2020)

1.6 Bow Tie Diagrams

Bow tie analysis (BTA), or the bow tie methodology, is a barrier-based risk management tool (Rayner Brown, Hastie, et al., 2021). It is becoming more prevalent as a PHA tool (Anderson et al., 2016), and demonstrates how threats can lead to the loss of control of a hazard and how this unsafe condition can develop into undesired consequences (Rayner Brown, Hastie, et al., 2021). Bow tie diagrams are excellent visualization and communication tools (Anderson et al., 2016) that can support the analysis, management, and communication of both process and non-process industry risks (CCPS/EI, 2018). A standard bow tie diagram is illustrated in Figure 1-4.

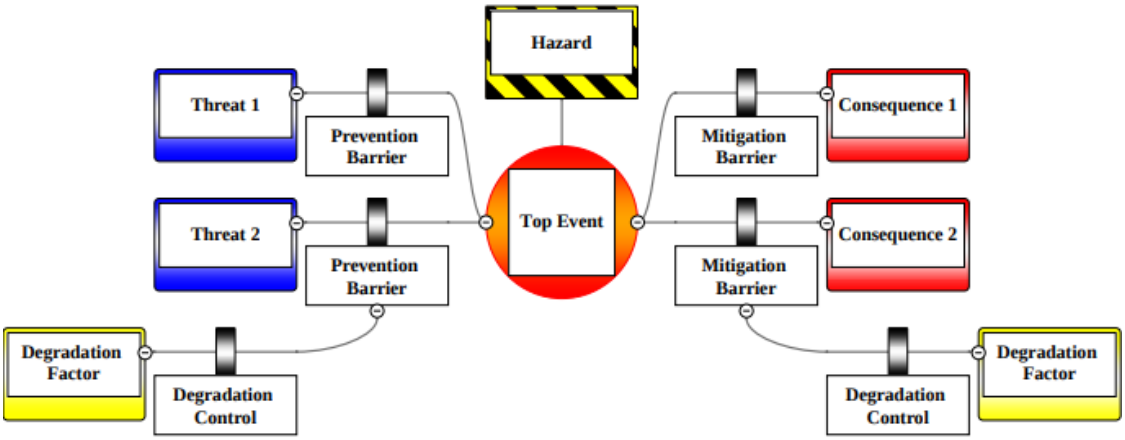

Figure 1-4. A standard bow tie diagram (CCPS/EI, 2018)

Bow tie diagrams are composed of eight elements: a hazard, a top event, threats, consequences, prevention barriers, mitigation barriers, degradation factors (also referred to as escalation factors), and degradation factor controls. The hazard is a potentially harmful operation, activity, or material. It provides clarity on the source of risk and defines the scope of the bow tie diagram. The top event describes the loss of control of the hazard. Threats are the potential causes of the top event, and consequences are the unwanted outcomes of the top event that can lead to damage or harm. Barriers are the measures that can prevent the threats from causing the top event or mitigate the consequences. Degradation factors are the conditions that reduce the effectiveness of the barriers, and degradation factor controls maintain the barriers by helping to defeat the degradation factors (CCPS/EI, 2018).

1.7 Human Behaviour and Human and Organization Factors

The International Association of Oil & Gas Producers (IOGP) defines human factors as "the term used to describe the interaction of individuals with each other, with facilities and equipment, and with management systems" (CCPS/EI, 2018, p. 69). IOGP also states that

the working environment and culture both influence this interaction. In BTA, human and organizational factor (HOF) issues can appear in several elements: as part(s) of prevention and mitigation barriers, degradation factors, and as part(s) of degradation factor controls. Human behaviour can have both positive (expected and exemplary behaviours) and negative (human error and violations) aspects. Bow tie diagrams typically address human error and violations and organizational factors in degradation factors (CCPS/EI, 2018). In the context of the COVID-19 pandemic, many degradation factors are related to human behaviour and HOF (Rayner Brown, VanBerkel, et al., 2021).

The common HOF categories of degradation factors are slips and lapses, mistakes, unintended violation, situational violations, organizational optimizing, personal optimizing, and recklessness (Rayner Brown, VanBerkel, et al., 2021). Table 1-1 lists the common HOF categories and the corresponding guidewords/phrases that describe them. Categorizing degradation factors with respect to the common HOF categories can help identify degradation factor controls (Rayner Brown, VanBerkel, et al., 2021). Recklessness, slips and lapses, and mistakes can be difficult to treat in bow ties, so degradation factors in these categories are generally not generated during workshop brainstorming (CCPS/EI, 2018).

Table 1-1. Common HOF categories and corresponding guidewords/phrases (adapted from CCPS/EI, 2018)

HOF Category	Guideword/phrase
Slips and lapses	"Oops"
Mistakes	"I thought I did it the right way"
Unintended violation	"I was not aware" "I did not understand"
Situational violation	"I cannot get the job done if I follow the rules, but I did the job anyway"
Organizational optimizing	"It was better for the company to do it that way"

HOF Category	Guideword/phrase
Personal optimizing	“It suited me better to do it that way”
Recklessness	“I did not think or care about the consequences”

1.8 Bow Tie ISD Protocol

PHA provides an opportunity to explicitly consider ISD within the framework of PSM. A protocol was previously developed by Dalhousie University researchers to integrate ISD into BTA (as a PHA tool). This protocol includes the use of a collection of specific, practical applications of ISD, referred to as example-based guidance, to identify ISD opportunities within the bow tie (Rayner Brown, Hastie, et al., 2021). This protocol is shown in Figure 1-5.

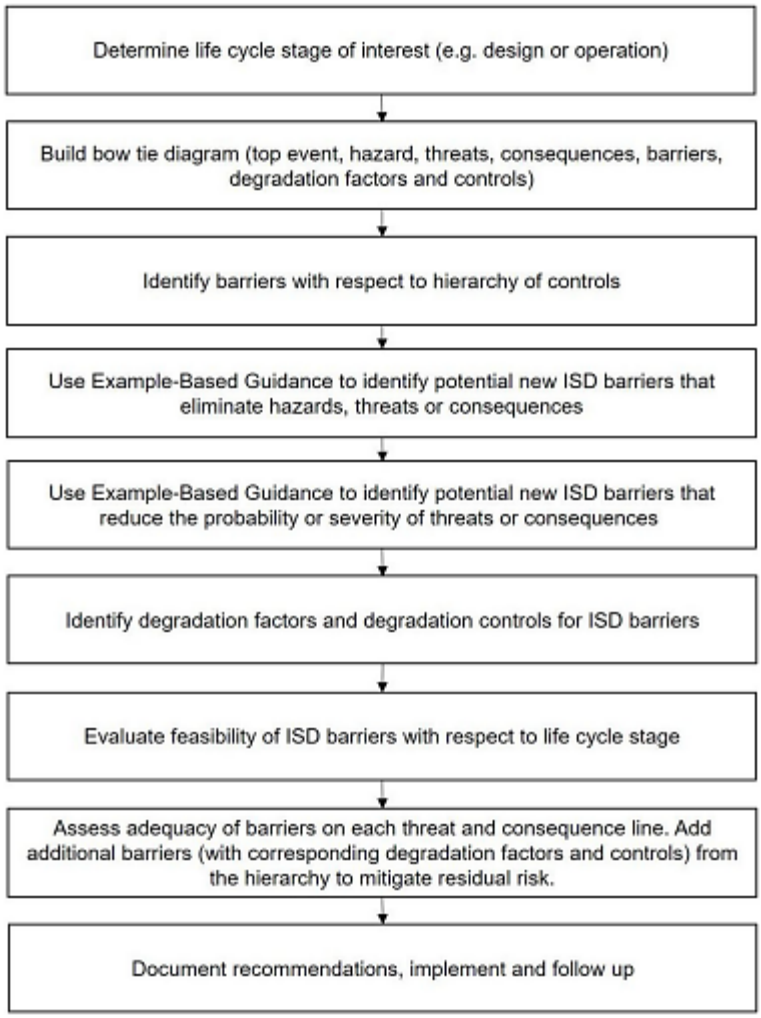

Figure 1-5. ISD protocol for BTA (Rayner Brown et al., 2021)

1.9 Industrial Involvement in Research

This research is part of a collaborative Natural Sciences and Engineering Research Council of Canada (NSERC) Alliance grant. Official research partnership involves Dalhousie University and Memorial University of Newfoundland, and official industry partnership includes the Nova Scotia Health Authority. Additional partnerships with the IWK Health Centre and the BC Forest Safety Council (BCFSC) have been developed, and online

COVID-19 resources for a Bluewater Association for Safety, Environment, and Sustainability (BASES) member facility have been used.

It must be noted that this project was proactive and did not arise in response to any specific outbreak occurrences. Rather, it was developed from the perspective of quality improvement through the preventative analysis of a hazard.

1.10 Organization of Thesis Document

The first two chapters describe the background of the COVID-19 pandemic, the hierarchy of controls, bow tie diagrams, the bow tie ISD protocol, and the applications of bow tie diagrams in healthcare and as communication tools. The next four chapters describe the research with the IWK Health Centre and the BCFSC, the research on the BASES member facility COVID-19 barriers, and the research on bow tie communication tools. Finally, the document closes with conclusions and recommendations for future work.

The thesis structure is as follows:

Chapter 1 presents an introduction to the project, along with the background information for the motivation, scope, and objectives of the research.

Chapter 2 describes the review of literature on the application of bow tie analysis in healthcare, and the application of bow tie diagrams as communication tools. A selection of case studies of the use of bow ties in various healthcare settings, including the COVID-19 pandemic, are outlined. The visual characteristics of bow tie diagrams are described, and the concept of a one-page document based on a COVID-19 bow tie diagram is introduced.

Chapter 3 describes the development of a bow tie diagram for a COVID-19 scenario at the IWK Health Centre, the evaluation of the COVID-19 barriers, and the recommendation of additional COVID-19 controls.

Chapter 4 describes the development of a bow tie diagram for a COVID-19 scenario at a BCFSC facility, the evaluation of the COVID-19 barriers, and the recommendation of additional COVID-19 controls.

Chapter 5 describes the identification of COVID-19 barriers, and corresponding degradation factors and degradation factor controls for a BASES member facility, and the evaluation of the COVID-19 barriers.

Chapter 6 describes the development of communication tools from the IWK Health Centre bow tie described in Chapter 4.

Chapter 7 provides the summary and conclusions of this thesis, and recommendations for future work.

Chapter 2 Background

This chapter, based on (Turner et al., 2021) with relevant excerpts, provides background information on various applications of the bow tie methodology in the healthcare industry, and on the use of bow tie diagrams as communication tools.

2.1 Application of bow ties in healthcare

The bow tie methodology is an increasingly popular PHA tool and is often employed in high-hazard industries. However, BTA has also been successfully used in medical safety applications (Ward et al., 2016).

2.1.1 Patient Safety in ICU

As compared to other non-critical hospital settings, the occurrence of serious adverse events and medical errors that threaten patient safety in an intensive care unit (ICU) setting is more frequent. A study published in 2016 (Abdi et al., 2016) used the bow tie methodology to analyze risks threatening patient safety in an ICU. The study was conducted for a 12-bed semi-closed medical ICU in a teaching hospital between late 2011 and early 2014.

The bow tie diagrams were developed by a multidisciplinary safety management team consisting of four physicians, five nurses, and one top management representative. One of the physicians was the team leader, and the bow tie methodology was initially presented to the team members by a facilitator.

Previous studies have expressed a need for context-specific PHA tools for healthcare settings. Teams that have applied BTA to healthcare settings reported several issues regarding the application, including the need for a knowledgeable facilitator. To increase

the adaptability of the methodology, Abdi et al. (2016) defined unit-specific top events and used a healthcare-specific classification for threats.

They found that the bow tie methodology is a feasible tool for proactive risk management in an ICU. The bow tie diagrams allowed team members to generate practical solutions to address deficiencies and promoted the clinicians' awareness regarding errors and conditions that might create undesired issues within their practice. The visualization of the diagrams also facilitated comprehension of the required barriers for safer operations in the ICU. However, BTA was determined to be time-consuming, with the reliability of the outputs depending on the reliability of the inputs. In general, the study found BTA to be capable of being a useful tool in ICU safety improvement programs (Abdi et al., 2016).

2.1.2 Surgical Instrument Retention

Research presented in 2016 applied the bow tie methodology to analyze the risk of surgical instrument retention (Ward et al., 2016). Although it is a rare occurrence, surgical instrument retention following central venous catheterization (CVC) presents a significant risk. CVC is a widely used medical procedure, but the risks of guidewire retention following the procedure are not as low as reasonably practicable (Chatzimichailidou et al., 2018).

For this research, the top event was defined as a guidewire being retained inside a patient. Several design solutions were identified, resulting in five additional prevention barriers and six mitigation barriers. The team found the links between the bow tie diagram elements to be helpful, and the diagram itself to be useful in identifying further opportunities for safety improvements. This research found that BTA is an effective tool to systematically display and examine the threats, consequences, and prevention and mitigation barriers associated

with an incident of guidewire retention. It also expresses that perhaps bow tie diagrams can be an effective communication tool. Bow ties were thus determined to be useful as a proactive tool to examine where gaps exist in broader issues with guidewire use in CVC procedures (Ward et al., 2016).

2.1.3 Anaesthesia

Due to the complex interaction of multiple hazards, and the potential for serious adverse outcomes, risk management is an important aspect of anaesthesia practice. A study published in 2016 applied the bow tie methodology to the analysis of risks associated with anaesthesia (Culwick et al., 2016).

The work identified several potential uses for bow tie diagrams in anaesthesia risk management including understanding risks, teaching risk management, demonstrating risk management strategies, proactively identifying weaknesses in risk management, and investigating clinical incidents. Clinical risk management in anaesthesia currently includes predominantly retrospective and reactive tools; BTA is a useful tool to proactively identify and understand risks as well as investigate incidents. Additionally, bow tie diagrams facilitate teaching and multidisciplinary discussions regarding risk analysis, helping healthcare professionals to understand and respond to challenges (Culwick et al., 2016).

2.1.4 Primary Healthcare

Primary healthcare relies on a variety of measures to manage risks to patient health and/or safety. A 2016 research paper reported an informal evaluation that explored the potential benefits of the application of the bow tie methodology to primary healthcare (McLeod & Bowie, 2018).

At least five potential benefits were identified, including improved recognition and understanding of barriers, raised awareness in the healthcare community and with stakeholders of the effectiveness of the barriers, understanding degradation factors and the required degradation factor controls, knowing who is responsible for the implementation, support, and maintenance of barriers and degradation factor controls, and awareness of how decisions and actions can cause barriers and degradation factor controls to fail. The evaluation determined that BTA has the potential to be applied to the risk management of serious events in primary healthcare.

Even though there are clear potential benefits, the evaluation reported concerns about the practicality and logistics of implementing the bow tie methodology in healthcare. Although the methodology seems relatively easy to implement, some of the terminology and concepts may not be intuitive to healthcare professionals. To be capable of developing bow tie diagrams to an adequate quality standard without relying on supports from external sources like external facilitators, training, supports, and resources would be required for the primary healthcare community (McLeod & Bowie, 2018).

2.1.5 Medication

Adverse drug effects (ADEs) occur frequently, and many are the result of systematic medication errors and organizational failure. Many healthcare organizations are working to improve patient medication safety. A study published in 2009 applied the bow tie methodology to prospective analysis of medication risks. The study was performed between January and December 2005 in a large teaching hospital and a large general hospital (Wierenga et al., 2009).

To determine the top events specific to medication safety, an external safety expert interviewed an internal medicine physician, a surgeon, a paediatrician, two nurses, two hospital pharmacists, and a pharmacy technician. At one hospital, multidisciplinary teams consisting of physicians, nurses, and pharmacists were organized to develop the bow tie diagrams. At the other hospital, the bow tie diagrams were developed by the departments of internal medicine and surgery.

The study found BTA to be an appropriate tool for prospective analysis of medication safety risks in a hospital. It gave team members insight into medication-related risks, increased safety awareness, and motivated team members to prioritize potential safety improvements. However, team members found the large amount of information collected in the bow tie diagrams difficult to interpret, and the bow tie methodology to be time consuming (Wierenga et al., 2009).

2.1.6 COVID-19 Pandemic

In April 2020, the Energy Institute/Centre for Chemical Process Safety (EI/CCPS) published a white paper demonstrating the use of bow tie analysis to model and communicate hazardous scenarios regarding contracting COVID-19 (Manton et al., 2020). This fundamental document provided validation for the work being undertaken at that time by a joint Dalhousie/Memorial research team (Rayner Brown, VanBerkel, et al., 2021). Since early 2020, bow tie diagrams concerned with the prevention and control of COVID-19 have been developed from different perspectives (CGE Risk, 2021). Rayner Brown, VanBerkel, et al. (2021) developed bow tie diagrams to model a scenario associated with contracting COVID-19 for the following specific receptor groups: immunocompromised individual, resident in a long-term care facility, primary care giver, grocery store employee,

paramedic, nurse, elementary school student, hair salon patron (based on guidance in the province of Nova Scotia, Canada), and fitness studio patron (also based on guidance in the province of Nova Scotia, Canada).

2.2 Application of Bow Ties as Communication Tools

As a visual tool, bow tie diagrams can communicate hazardous scenarios to a range of audiences at all levels of an organization (Rayner Brown, VanBerkel, et al., 2021). They are suitable to be displayed on posters to highlight key risk control concerns (Lewis & Smith, 2010), and they have been found to enhance communication about risk awareness and management in stakeholder groups (Gerkensmeier & Ratter, 2018).

Bow tie diagrams can meet the risk communications needs for many different audiences, including design teams (capital projects), regulators, contractors, management, local community, top management, and the workforce. For different audiences, and for different applications, bow tie diagrams can be presented in different formats (CCPS/EI, 2018):

- The Introductory Level only shows the hazard, top event, threats, and consequences.
- The Standard Bow Tie Level (without degradation factors) shows the information of the introductory level and adds the prevention and mitigation barriers, degradation factors, and degradation factor controls; this format is the most common.
- For the Standard Bow Tie Level (with degradation factors), the level of display would depend on the needs of the audience; the extra information in this level can add complexity to the diagram.

- The Enhanced Standard Bow Tie Level (with metadata) shows the information of the previous level and displays the relevant metadata beneath each barrier; examples of metadata include barrier type, barrier functionality, and criticality.
- The Multi-Level Bow Tie Format shows the lower-level controls that support the standard bow tie degradation factor controls; these controls are not shown in standard bow tie diagrams, but they are important controls.

Bow tie software, including BowTie XP (the software used by the research team) can support different levels of display without permanently deleting any elements or details. This facilitates matching the display to the needs of a particular audience (CCPS/EI, 2018). However, when presenting bow tie diagrams in documents or in print, it can be difficult to include information above the standard bow tie level (without degradation factors) while maintaining the readability of the diagram.

Regarding the COVID-19 pandemic, bow tie diagrams are an excellent communication tool to disseminate key safety information to a workforce. Risktec has proposed that information for each barrier on a COVID-19 bow tie diagram could be easily communicated to workers in a one-page summary. This one-pager could include the following information: what the barrier is, what it does, how it performs, how it is tested, where workers can find documents with further information, and who workers can contact for further information (Risktec, n.d.).

Chapter 3 IWK Bow Tie

This chapter, based on Turner et al. (2021) with relevant excerpts, describes the research performed in collaboration with the IWK Infection Prevention and Control (IPAC) team. The chapter provides details of the bow tie scope; the development of the bow tie diagram; the evaluation of the barriers, degradation factors, and degradation factor controls; the results and conclusions of this research; and recommended additional barriers and degradation factors that could be considered by the IPAC team.

3.1 Bow Tie Scope

The scope of the bow tie diagram was defined by the hazard and top event. Using terminology that follows the accepted distinction between COVID-19 and SARS-CoV-2, the hazard was "Novel coronavirus in human population", with the top event specific to a receptor group at the IWK Health Centre contracting COVID-19 (Rayner Brown, VanBerkel, et al., 2021).

Input from the IPAC team helped further define the top event. Based on team roles and responsibilities, and the organization of the facility, the specific receptor group was defined as patient and family in acute care. Therefore, the top event was "Patient and family in IWK Health Centre in acute care contracts COVID-19". The IWK Health Centre, located in Halifax, Nova Scotia, is a tertiary women's and children' health centre.

3.2 Bow Tie Development

The bow tie diagram was developed through collaborative workshops with the IPAC team. Two workshops took place in-person (on-site) in April 2021 and July 2021. Workshop personnel consisted of the IPAC team (four registered nurses, two specialists in

performance improvement, a director, and a physician director), a scribe assistant (current author), and an experienced facilitator/scribe. One of the performance improvement specialists organized and scheduled the workshops. The facilitator/scribe lead the workshops and recorded the bow tie elements. The scribe assistant recorded any assumptions made during the workshops and documented additional discussions and items of interest. The IPAC team members provided expert input.

During the first workshop, the facilitator/scribe introduced the IPAC team members to the bow tie methodology and bow tie diagram elements. The IPAC team defined the top event, listed all possible threats and consequences, and began identifying prevention and mitigation barriers. A second workshop was initially scheduled for later in April 2021, but due to a third wave of COVID-19 cases in Nova Scotia and the resulting lockdown, the session was delayed until July 2021.

During the second workshop, the team reviewed the work that had been done during the first workshop and finished identifying prevention and mitigation barriers. Due to the limited time available for the workshop, the team listed only the degradation factors and controls specific to the IWK Health Centre. Following the workshops, the bow tie diagram was updated by the scribe assistant to include degradation factors and controls for common barriers (Rayner Brown, VanBerkel, et al., 2021). Due to space considerations, Figure 3-1 shows an excerpt of the bow tie diagram, including the hazard, top event, threats, and consequences. The full bow tie diagram is given in Appendix A.

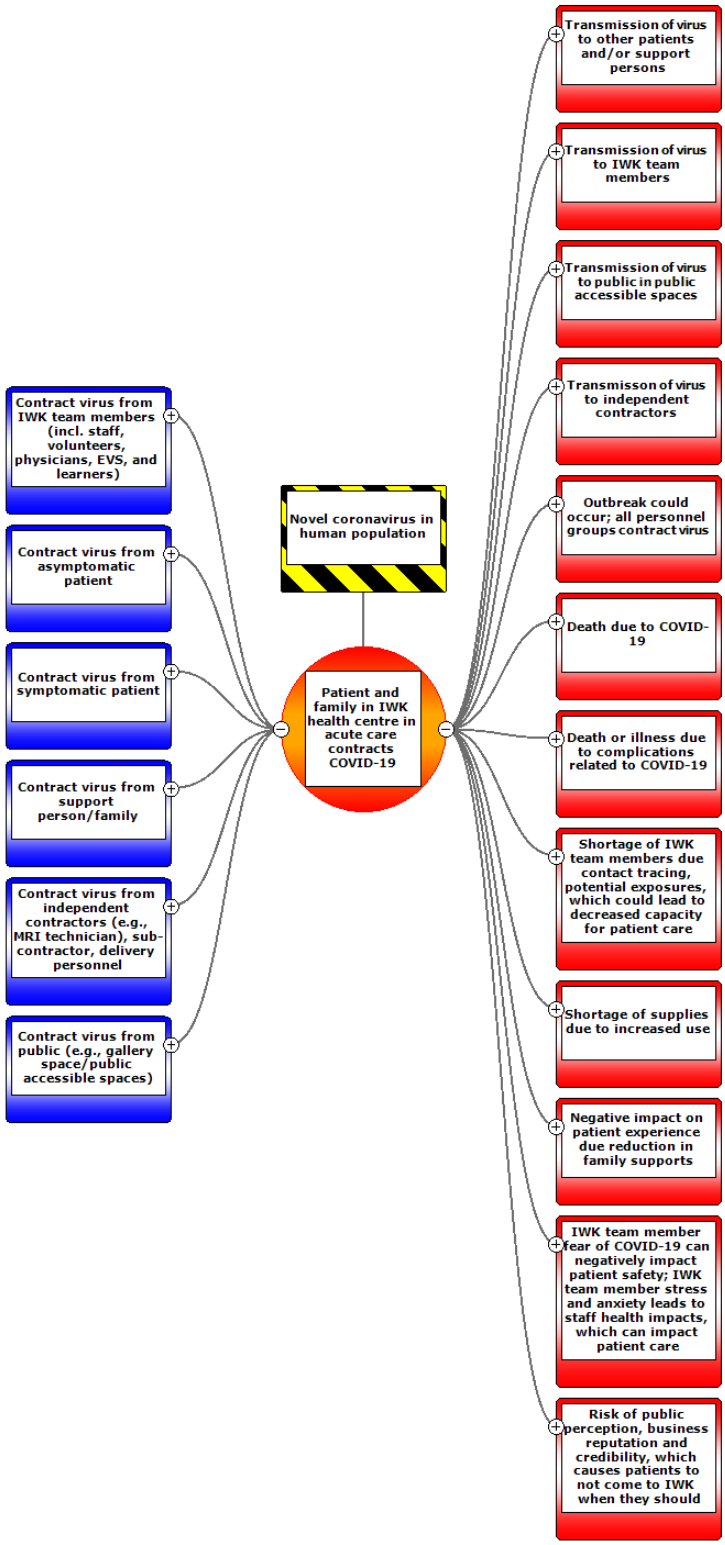

Figure 3-1. Excerpt of bow tie diagram representing a patient or family member at the IWK Health Centre in acute care contracting COVID-19

3.3 Barrier Evaluation

The objectives of this research include evaluating prevention and mitigation measures currently in place, and exploring additional measures based on inherently safer design (ISD) and the hierarchy of controls (HOC). This barrier evaluation methodology is based on the ISD protocol for bow tie analysis (BTA) protocol developed by Rayner Brown, Hastie, et al. (2021), as previously described in Chapter 1. The first step is to examine and categorize the barriers with respect to the HOC. The next step is to evaluate the degradation factors and degradation controls. The final step is to use example-based guidance and supporting literature to identify additional barriers and degradation factor controls based on ISD and the HOC.

3.3.1 Barrier Categorization with Respect to the Hierarchy of Controls

To begin the barrier evaluation for the IWK bow tie diagram, the identified barriers were categorized with respect to the HOC. As described in Chapter 1, the types of controls in the HOC are ISD, passive engineered, active engineered, and administrative. Table 3-1 provides the COVID-19 barriers currently in place at the IWK Health Centre in acute care. In Table 3-1, the barriers are organized in the order in which they first appear in the bow tie diagram, as read from top-left to bottom-right.

Table 3-1. IWK Health Centre COVID-19 barriers (categorized with respect to the HOC)

Barrier	Barrier Type
Immunization of team members that are vaccine-eligible	Passive Engineered
Exclusion of IWK team members who were in moderate or high-risk exposure settings	Administrative (with aspects of ISD)
Exclusion of any IWK team members with COVID-19 from work/health centre	Administrative (with aspects of ISD)

Barrier	Barrier Type
Self-monitor for COVID-19 symptoms and follow-up with IWK Occupational Health, Safety, & Wellness (OHSW)	Administrative
Medical grade face mask worn by IWK team members	Administrative
Practice good hand-hygiene at 4 Moments	Administrative
Restricted access to communal areas (e.g., access to playrooms, closed kitchenette, laundry room)	Administrative (with aspects of ISD)
Pre-screening for planned visits to determine if patient has an exposure risk	Administrative (with aspects of ISD)
Door screening questions to determine if patient or family member/support person has an exposure risk	Administrative (with aspects of ISD)
Single patient rooms assigned for both inpatient and pediatric ambulatory care asymptomatic patients	Administrative (with aspects of ISD)
Physical distancing in public areas and, when possible, during assessments	Administrative (with aspects of ISD)
Limitations around day passes (exceptions only)	Administrative (with aspects of ISD)
Use of additional precautions based on risk assessment, including use of airborne infection isolation room (AIIR), as required (e.g., exposure history)	Administrative
Universal pandemic protections (UPP) worn by all direct care providers	Administrative
Medical grade face mask worn by patient in public areas and, when possible, during assessments	Administrative
Practice good hand hygiene and sneeze/cough etiquette	Administrative
Universal COVID-19 testing for all admissions and prior to all surgical procedures	Administrative
Routine cleaning and disinfection of high-touch surfaces and infection control practices (e.g., decontamination of equipment)	Administrative
Pre-screening for planned visits and re-book if patient meets screening criteria and appointment is non-urgent	Administrative (with aspects of ISD)
Door screening questions and alert care area for direct placement for symptomatic patients	Administrative (with aspects of ISD)
Single patient rooms assigned and designated rooms on inpatient wards for symptomatic patients	Administrative (with aspects of ISD)
Restrictions in place for public area access; isolation of patient and family/support person in room and escorted through hospital	Administrative (with aspects of ISD)
Support persons restrictions	Administrative (with aspects of ISD)

Barrier	Barrier Type
Pre-screening for planned visits to determine if support person has an exposure risk; instructed to find alternate if they meet the criteria	Administrative (with aspects of ISD)
Complete pre-travel, pre-screening form for contractors developed with IWK Occupational Health, Safety, & Wellness (OHSW) and quarantine if deemed necessary	Administrative (with aspects of ISD)
Exclusion of contractors who were in moderate or high-risk exposure settings	Administrative (with aspects of ISD)
Exclusion of any contractors with COVID-19 from work/health centre	Administrative (with aspects of ISD)
Additional screening and additional COVID-19 testing for contractors	Administrative
Recommendation that patients do not go to gallery space	Administrative (with aspects of ISD)
Shutdown gallery lounge space for Ronald McDonald and food pickup moved to internal screened area	Administrative (with aspects of ISD)
Food services closed during times of high-risk	Administrative (with aspects of ISD)
Gift shop services offered online instead of in-person	Administrative (with aspects of ISD)
Additional cleaning of gallery and dedicated Environmental Services (EVS)	Administrative
Communication to community partners to discourage visits to food vendors in gallery	Administrative
Contact tracing and testing in partnership with Public Health and Occupational Health, Safety, & Wellness (OHSW)	Administrative
Minimize the number of people caring for the patient at a given time	Administrative (with aspects of ISD)
COVID-19 testing for identification and isolation of patients	Administrative
Limited public access to health centre	Administrative (with aspects of ISD)
No entry by independent contractors to COVID-19 patient rooms	Administrative (with aspects of ISD)
Hospitalization, including therapeutics (e.g., medication) and supportive management (e.g., ventilators, hydration)	Administrative
Limitations on number of team members in area, including staggering breaks	Administrative (with aspects of ISD)
The Good Neighbour Protocol to facilitate sharing of human resources among local health centres	Administrative
Access to provincial PPE resources	Administrative

Barrier	Barrier Type
Sourcing of alternative PPE and approval programs for alternates	Administrative
PPE inventory access control	Administrative
Re-use of reusable PPE (e.g., gowns)	Administrative
Critical supply list projections to communicate supplies and any shortages, including quality assurance checks on products, PPE dashboard, and communications with supplier	Administrative
PPE coordinator role to take inventory of PPE in units during periods of high demand	Administrative
Track usage of N95 respirators to replenish supplies	Administrative
Planning for N95 reprocessing if needed during periods of high demand	Administrative
Exception process for support person/family for critical situations (i.e., pediatric patient with no alternate) with Director approval	Administrative
Encourage patients and family/support persons to use electronic modes of communication (iPads available to borrow), meal cards provided, free Wi-Fi access	Administrative
Pandemic education	Administrative
Rapid communication and response to personnel emails	Administrative
Leadership support and team leads strategize with key leaders to support team members, including effective communication and clear executive involvement and direction	Administrative
Town halls for IWK team members	Administrative
Maintain confidentiality of IWK patients	Administrative
Monitor media and provide proactive press releases; communication efforts	Administrative
Active social media presence	Administrative
Address potential perception/reputation issues proactively in government updates	Administrative

IWK team members are the only group included in the immunization barrier because immunization for patients, family members/support persons, and the public is a public health measure that the IWK Health Centre cannot control. Additionally, this bow tie diagram was developed before the province of Nova Scotia began requiring proof of

vaccination for discretionary activities in October 2021, and for certain groups including healthcare workers in November 2021 (Petracek, 2021).

The 4 Moments of hand hygiene describe when, while providing direct care, healthcare professionals should wash their hands. These moments are (Public Health Ontario, n.d.):

1. Before initial patient/patient environment contact
2. Before aseptic procedure, like changing a dressing or drawing blood
3. After body fluid exposure risk (and after glove removal)
4. After patient/patient environment contact

The Good Neighbour Protocol is an agreement that was signed by healthcare unions, including the Nova Scotia Nurses' Union (NSNU), in response to the H1N1 pandemic. The agreement aims to preserve health services and protect healthcare workers in the event of emergencies, such as pandemics and natural disasters. The purpose of the protocol is to facilitate, in the event of an emergency, the sharing of human resources among jurisdictions (NSNU, n.d.).

3.3.2 Evaluation of Degradation Factors

The next step was to evaluate the degradation factors identified for each barrier. In the context of the COVID-19 pandemic, many degradation factors are related to human behaviour and human and organizational factors (HOF). As described in Chapter 1, the common HOF categories of degradation factors are slips and lapses, mistakes, unintended violation, situational violations, organizational optimizing, personal optimizing, and recklessness (Rayner Brown, VanBerkel, et al., 2021). Table 3-2 provides the COVID-19

barriers currently in place at the IWK Health Centre in acute care and the corresponding degradation factors.

Table 3-2. IWK Health Centre COVID-19 barriers and corresponding degradation factors (categorized with respect to the HOF categories)

Barrier	Degradation Factor	Degradation Factor Category
Immunization of team members that are vaccine-eligible	Vaccine hesitancy	Personal optimizing
Exclusion of IWK team members who were in moderate or high-risk exposure settings	IWK team member not honest about travel history or symptoms	Personal optimizing
Self-monitor for COVID-19 symptoms and follow-up with IWK Occupational Health, Safety, & Wellness (OHSW)	IWK team member not honest about travel history or symptoms	Personal optimizing
	Contractor not honest about travel history or symptoms	Personal optimizing
Medical grade face mask worn by IWK team members	Face mask worn improperly	Unintended violation, mistake, situational violation, or personal optimizing
Practice good hand-hygiene at 4 Moments	Procedure not followed due to work demands (e.g., too busy, hands are too full)	Situational violation
	Procedure not followed due to skin breakdown	Situational violation
	Misperception of when hand hygiene is required (e.g., did not touch anything)	Unintended violation or mistake
	Forgetfulness	Slip or lapse
	Poor leadership example (e.g., if one senior person does not follow procedure, junior person does not)	Situational violation
	Complacency	Personal optimizing

Barrier	Degradation Factor	Degradation Factor Category
Pre-screening for planned visits to determine if patient has an exposure risk	Unable to contact/reach patient	Situational violation
	Using out of date script, or ad-libbing	Situational violation
	Unaware that interpretation services are needed	Unintended violation
	Limited resources; time and staffing challenges (including staff turnover)	Unintended violation
Door screening questions to determine if patient or family member/support person has an exposure risk	Patient not honest about travel history or symptoms	Personal optimizing
	Support person/family not honest about travel history or symptoms	Personal optimizing
	Pediatric patient has no alternate support person	Situational violation
	Door screening not performed at night-time	Organizational optimizing
	Visitor tailgates or circumnavigates door screening	Personal optimizing or recklessness
Single patient rooms assigned for both inpatient and pediatric ambulatory care asymptomatic patients	Financial pressure to open the warded room	Organizational optimizing
Physical distancing in public areas and, when possible, during assessments	Difficulty managing traffic	Situational violation
	Physical distancing not followed	Unintended violation, mistake, or personal optimizing

Barrier	Degradation Factor	Degradation Factor Category
Use of additional precautions based on risk assessment, including use of airborne infection isolation room (AIIR), as required (e.g., exposure history)	Door to AIIR propped open due to lack of understanding or work demands	Unintended violation, mistake, or situational violation
	AIIR preventative maintenance not completed (e.g., pressures, filters, maintain higher levels of air exchanges)	Unintended violation, mistake, organizational violation, situational violation, or personal optimizing
	Incorrect risk assessment (e.g., should be using additional precautions when not)	Unintended violation or mistake
Universal pandemic protections (UPP) worn by all direct care providers	PPE shortage	Situational violation
	PPE worn improperly	Unintended violation, mistake, situational violation, or personal optimizing
Medical grade face mask worn by patient in public areas and, when possible, during assessments	Face mask worn improperly	Unintended violation, mistake, or personal optimizing
Practice good hand hygiene and sneeze/cough etiquette	Proper hand washing method not followed	Unintended violation, mistake, situational violation, or personal optimizing
Universal COVID-19 testing for all admissions and prior to all surgical procedures	False negative COVID-19 test results (Flanagan, 2021)	Situational violation
Routine cleaning and disinfection of high-touch surfaces and infection control practices (e.g., decontamination of equipment)	Proper cleaning procedure not followed	Unintended violation, mistake, or personal optimizing
Pre-screening for planned visits and re-book if patient meets screening criteria and appointment is non-urgent	Patient not honest about travel history or symptoms	Personal optimizing
Door screening questions and alert care area for direct placement for symptomatic patients	Patient not honest about travel history or symptoms	Personal optimizing

Barrier	Degradation Factor	Degradation Factor Category
Single patient rooms assigned and designated rooms on inpatient wards for symptomatic patients	Financial pressure to open the warded room	Organizational optimizing
Support persons restrictions	Inability to identify support persons, leading to too many people in health centre	Situational violation
Complete pre-travel, pre-screening form for contractors developed with IWK Occupational Health, Safety, & Wellness (OHSW) and quarantine if deemed necessary	Contractor not honest about travel history or symptoms	Personal optimizing
Exclusion of contractors who were in moderate or high-risk exposure settings	Contractor not honest about travel history or symptoms	Personal optimizing
Additional screening and additional COVID-19 testing for contractors	False negative COVID-19 test results (Flanagan, 2021)	Situational violation
Self-monitor for COVID-19 symptoms and follow-up with IWK Occupational Health, Safety, & Wellness (OHSW)	IWK team member or contractor not honest about travel history or symptoms	Personal optimizing
Recommendation that patients do not go to gallery space	Patient does not follow recommendation and goes to gallery	Personal optimizing or recklessness
Additional cleaning of gallery and dedicated Environmental Services (EVS)	Proper cleaning procedure not followed	Unintended violation, mistake, organizational violation, situational violation, or personal optimizing
Contact tracing and testing in partnership with Public Health and Occupational Health, Safety, & Wellness (OHSW)	False negative COVID-19 test results (Flanagan, 2021)	Situational violation

Barrier	Degradation Factor	Degradation Factor Category
Minimize the number of people caring for the patient at a given time	Teaching health centre, need to accommodate students and residents	Organizational optimizing
	Nurses are usually assigned 3-4 patients	Organizational optimizing
	An allied health team includes many members	Organizational optimizing
	Food services usually delivers food directly to patients	Organizational optimizing
COVID-19 testing for identification and isolation of patients	False negative COVID-19 test results (Flanagan, 2021)	Situational violation
The Good Neighbour Protocol to facilitate sharing of human resources among local health centres	Difficulty sharing human resources due to staff shortages at all health centres	Situational violation
Re-use of reusable PPE (e.g., gowns)	Central laundry down; unable to provide reusable PPE	Situational violation
Pandemic education	Misinformation driving fear and anxiety	Unintended violation or situational violation
	Overwhelming amount of information, and management of change; need to rapidly evolve and adapt	Situational violation
	Challenges with working through science in real-time; understanding the situation as it evolves; dealing with uncertainty	Situational violation

Vaccine hesitancy is defined as "delays in accepting or refusing vaccines despite the availability of vaccination services" (MacDonald & Dubé, 2018). There are many different reasons underlying vaccine hesitancy, even within a given province or territory. Vaccine

hesitancy also tends to occur in pockets or clusters, like in religious communities or groups focused on natural medicine (MacDonald & Dubé, 2018).

In this context, to "tailgate" means to enter the health centre unauthorized behind an authorized visitor. Tailgating (also known as piggybacking) can be either forced or accidental. A common workplace example of tailgating is an employee holding the door open for a visitor, allowing the unauthorized visitor access to the building (Meesons, n.d.).

Polymerase chain reaction (PCR) tests are considered our best tool for determining if someone has COVID-19; however, the tests are not accurate in 100% of cases. False positive results, where a patient tests positive despite not having COVID-19, are very rare while false negative results, where a patient tests negative despite having COVID-19, are more common. One cause of false negative results is that the patient is either too early or too late in their illness to test positive. Another cause is that the collected sample was too small, or the virus was not present at the point of collection (Flanagan, 2021).

3.3.3 Evaluation of Degradation Factor Controls

The next step in the barrier evaluation was to evaluate the identified degradation factor controls. Similar to the barriers, these were categorized with respect to the HOC. Table 3-3 provides the COVID-19 barrier degradation factors currently in place at the IWK Health Centre in acute care and the corresponding degradation factor controls.

Table 3-3. IWK Health Centre COVID-19 barrier degradation factors and corresponding degradation factor controls (categorized with respect to the HOC)

Degradation Factor	Degradation Factor Control	Degradation Factor Control Type
Vaccine hesitancy	Education and outreach (advertising, social media campaigns) (MacDonald & Dubé, 2018)	Administrative
	Target under-immunized sub-groups with tailored interventions (MacDonald & Dubé, 2018)	Administrative
	Remind team members by text, email, or mail as appropriate (MacDonald & Dubé, 2018)	Administrative
Face mask worn improperly	Pandemic education on proper use of PPE	Administrative
Misperception of when hand hygiene is required (e.g., did not touch anything)	Education	Administrative
	Supervision and training; on-the-spot feedback	Administrative
Poor leadership example (e.g., if one senior person does not follow procedure, junior person does not)	Auditing	Administrative
	Education	Administrative
Complacency	Auditing	Administrative
	Supervision and training; on-the-spot feedback	Administrative
Unable to contact/reach patient	Call patient back; try again	Administrative
	Layers of protection/multiple checks (at door and clinic)	Administrative
Using out of date script, or ad-libbing	Most up-to-date script kept online/on Intranet site	Administrative
Unaware that interpretation services are needed	Better flags for interpretation services in system	Administrative
Limited resources; time and staffing challenges (including staff turnover)	Volunteer recruitment	Administrative
Visitor tailgates or circumnavigates door screening	Visual cues and signage	Administrative (with aspects of ISD)

Degradation Factor	Degradation Factor Control	Degradation Factor Control Type
Financial pressure to open the warded room	Consultation with IPAC team	Administrative
Difficulty managing traffic	Decreased number of people in health centre	Administrative (with aspects of ISD)
	Capacity limits for elevators	Administrative (with aspects of ISD)
	Communications with surrounding area to encourage public to avoid health centre (when not needed	Administrative (with aspects of ISD)
	Health centre doors locked	Administrative
	Assessment of waiting area and capacity limits put in place	Administrative (with aspects of ISD)
	Shutdown food services during key times	Administrative (with aspects of ISD)
	Physical distancing markers/cues on floor (Rayner Brown, VanBerkel, et al., 2021)	Administrative (with aspects of ISD)
	Posters, easily accessible and downloadable (signage) (Rayner Brown, VanBerkel, et al., 2021)	Administrative (with aspects of ISD)
	Separate entrances for children's and women's patients	Administrative (with aspects of ISD)
Physical distancing not followed	Physical distancing markers/cues on floor (Rayner Brown, VanBerkel, et al., 2021)	Administrative (with aspects of ISD)
	Posters, easily accessible and downloadable (signage) (Rayner Brown, VanBerkel, et al., 2021)	Administrative (with aspects of ISD)
	Education (Rayner Brown, VanBerkel, et al., 2021)	Administrative
Door to AIIR propped open due to lack of understanding or work demands	Education	Administrative

Degradation Factor	Degradation Factor Control	Degradation Factor Control Type
Incorrect risk assessment (e.g., should be using additional precautions when not)	Education of the person performing the risk assessment (online learning package, onboarding, orientation)	Administrative
	Auditing	Administrative
PPE worn improperly	Pandemic education on proper use of PPE	Administrative
Proper hand washing method not followed	Education, training	Administrative
Proper cleaning procedure not followed	Education, training	Administrative
Inability to identify support persons, leading to too many people in health centre	Bracelet system for support persons who are allowed onsite	Administrative (with aspects of ISD)
Patient does not follow recommendation and goes to gallery	Physical distancing markers/cues on floor (Rayner Brown, VanBerkel, et al., 2021)	Administrative (with aspects of ISD)
	Gallery seating areas removed, and picnic tables added outside	Administrative (with aspects of ISD)
Teaching health centre, need to accommodate students and residents	Encouragement to not take entire team into rounds (only 2-3 team members)	Administrative (with aspects of ISD)
Nurses are usually assigned 3-4 patients	Nurses assigned to a COVID-positive patient will only work with COVID-positive patients that shift (could only be 1 patient)	Administrative (with aspects of ISD)
An allied health team includes many members	Encouragement of care that can be provided without direct contact	Administrative (with aspects of ISD)
Food services usually delivers food directly to patients	Food tray drops at nurses' station and nurses deliver food to patients	Administrative (with aspects of ISD)

Degradation Factor	Degradation Factor Control	Degradation Factor Control Type
Difficulty sharing human resources due to staff shortages at all health centres	Training and onboarding so unregulated persons can help (i.e., pop-up COVID-19 testing)	Administrative (with aspects of ISD)
	Elevate medical students and nursing students to perform other work	Administrative (with aspects of ISD)
	Early licensing of medical students and nursing students to increase workforce	Administrative (with aspects of ISD)
	Re-education fees waived for healthcare workers coming out of retirement	Administrative (with aspects of ISD)
Central laundry down; unable to provide reusable PPE	Switch to single-use PPE from existing suppliers, or source appropriate alternates at different suppliers	Administrative (with aspects of ISD)
Misinformation driving fear and anxiety	Peer-to-peer supports available	Administrative
	"Mythbuster" responses developed for new pandemic information that could be misinterpreted	Administrative
Overwhelming amount of information, and management of change; need to rapidly evolve and adapt	Face-to-face support available in real-time	Administrative
	Clear communication, emails; Intranet website	Administrative

3.4 Results and Discussion

Almost all the COVID-19 barriers identified in this bow tie diagram were administrative, and many of these administrative barriers were identified to have aspects of ISD. As described in Chapter 1, it should be noted that although the barriers incorporate ISD principles, they are still administrative. For the barriers that were administrative (with aspects of ISD), most were rooted in the strategy of minimization and the rest were rooted in the strategy of moderation. There was one passive engineered barrier, and none of the

identified barriers were active engineered or ISD. Due to the research team's understanding that many COVID-19 barriers rely on human behaviour (Rayner Brown, VanBerkel, et al., 2021), it was expected that most of the barriers identified in this bow tie diagram would be categorized as administrative or administrative (with aspects of ISD). These results show the importance of considering HOF in bow tie diagrams for COVID-19 scenarios, and the benefit of using an ISD mindset (Rayner Brown, VanBerkel, et al., 2021) to incorporate the ISD principles and concepts into barriers of other levels in the HOC (like administrative controls).

Of the identified degradation factors that were related to human behaviour and HOF, the most common categories were situational violation and personal optimizing. The next most common category was unintended violation, followed by mistakes, organizational optimizing, and recklessness and slips and lapses. Situational violations can be described as "I cannot get the job done if I follow the rules, but I did the job anyway", and personal optimizing can be described as "It suited me better to do it that way" (CCPS/EI, 2018, p. 7). With these two categories as the most common, it could be understood that many degradation factors in this bow tie diagram are the result of the COVID-19 barriers being inconvenient or less attractive than the way things were done before the COVID-19 pandemic. Additionally, IWK team members, patients, and family/support persons may be unaware that their actions are degrading the effectiveness of the barriers. These results show the importance of communicating how the COVID-19 barriers fit into the routines of the IWK team members, patients, and family/support persons and how these barriers can fail.

All the degradation factor controls identified in this bow tie were categorized as administrative or administrative (with aspects of ISD). As with the barriers, it was expected that most of the degradation factor controls would be categorized as administrative or administrative (with aspects of ISD). This seems reasonable given that many of the degradation factors were related to human behaviour and HOF.

3.5 Recommendations

Following the bow tie workshops, the IPAC team members were asked the following questions:

- Does the IPAC team have any resources they can share regarding recommended COVID-19 barriers for healthcare settings? This could include resources regarding identifying which barriers to implement, and resources on barriers focused on ISD.
- Are there any barriers that the IPAC considered that were not implemented? If yes, why were they not implemented?
- Does the IPAC team have any additional COVID-19 barriers that they would recommend?

The IPAC team stated that, in addition to extrapolation of what they already knew regarding infection prevention and control safety measures, the team had several meetings with the Nova Scotia Health Authority (NSHA) and attended webinars from the Society for Healthcare Epidemiology of America (SHEA). For more information regarding COVID-19 safety measures, the IPAC team recommended reviewing resources from the Centres for Disease Control and Prevention (CDC) and the Public Health Agency of Canada (PHAC).

Several resources from the CDC (CDC, 2020a, 2020b, 2021a, 2021b, 2021c, 2021d, 2021e) and the PHAC (Government of Canada, 2020) were reviewed and compared to the barriers and degradation factor controls identified in the bow tie diagram. Additionally, other resources considered for this research (BCCDC, 2020) and the lived experiences of the researchers were considered and compared to the bow tie diagram. The following table, Table 3-4, lists additional barriers or degradation factor controls that could be considered by the IWK Health Centre to prevent and mitigate the spread of COVID-19. These barriers and degradation factor controls were also categorized with respect to the HOC. It should be noted that although these controls do exist at the IWK Health Centre, they were not identified for the specific receptor group investigated.

Table 3-4. Additional COVID-19 barriers/degradation factor controls that could be considered by the IWK Health Centre (categorized with respect to the HOC)

Control	Control Type	Reference
When possible, conduct appointments over the telephone (or other telehealth resources) to reduce the number of in-person patients	ISD (Minimization)	(CDC, 2020; Government of Canada, 2020)
Place physical barriers (e.g., plexiglass) in waiting areas	Passive engineered	(BCCDC, 2020; CDC, 2021b)
Maintain adequate ventilation in single rooms or wards for COVID-19 patients (60 L/s per patient)	Passive engineered	(CDC, 2021)
When possible, avoid procedures that can generate fine aerosols	Administrative (with aspects of ISD)	(CDC, 2021)
Develop and maintain a communication plan for IWK team members, patients, and the community (could include virtual town halls, daily communications with local leadership, calls with partners, emails and phone conferences with team members, and media briefs)	Administrative	(CDC, 2020)

Chapter 4 BCFSC Bow Tie

This chapter describes the research performed in collaboration with the British Columbia Forest Safety Council (BCFSC). It provides details of the bow tie scope; the development of the bow tie diagram; the evaluation of the barriers, degradation factors, and degradation factor controls; the results and conclusions of this research; and recommended barriers and degradation factor controls from the provinces of Nova Scotia (NS) and British Columbia (BC).

4.1 Bow Tie Scope

As with the bow tie diagram described in Chapter 3, the scope of this bow tie diagram was defined by the hazard and top event. Using terminology that follows the accepted distinction between COVID-19 and SARS-CoV-2, the hazard was "Novel coronavirus in human population" (Rayner Brown, VanBerkel, et al., 2021). BCFSC is the Health and Safety Association (HSA) for the forest sector in British Columbia, Canada; the British Columbian forest sector includes forest harvesting, sawmills, and wood pellet manufacturing. Based on the Dalhousie research team's previous research collaboration with BCFSC and the Wood Pellet Association of Canada (WPAC) (WPAC, n.d.), wood pellet manufacturing facilities were identified as an area of interest and the top event was defined as "Staff member at wood pellet facility contracts COVID-19".

4.2 Bow Tie Development

The bow tie diagram was developed through a "single-analyst" approach by two Dalhousie researchers, including the current author. In this thesis, a "single-analyst" approach describes developing the bow tie without the direct input of the industry partner as in a

collaborative workshop. The researchers collected COVID-19 resources available online from the BCFSC, British Columbia Centre for Disease Control (BCCDC), and WorkSafeBC (BCCDC, 2020; BCFSC, 2020a, 2020b, 2020c, 2020d, 2020e, 2020f, 2020g, 2020h, 2020i, 2020j, 2021; WorkSafeBC, 2020) and reviewed them prior to developing the bow tie.

The researchers met virtually in June 2021 over Microsoft Teams. The bow tie diagram was developed primarily using the resources from the BCFSC, degradation factors and controls for common barriers (Rayner Brown, VanBerkel, et al., 2021), and recommended barriers and degradation factor controls from the provinces of Nova Scotia and British Columbia.

The bow tie diagram was reviewed by a BCFSC representative in October 2021, who provided expert input and clarification on the implementation of COVID-19 barriers in BCFSC wood pellet facilities. Due to space considerations, Figure 4-1 shows an excerpt of the bow tie diagram, including the hazard, top event, threats, and consequences. The full bow tie diagram is available in Appendix B.

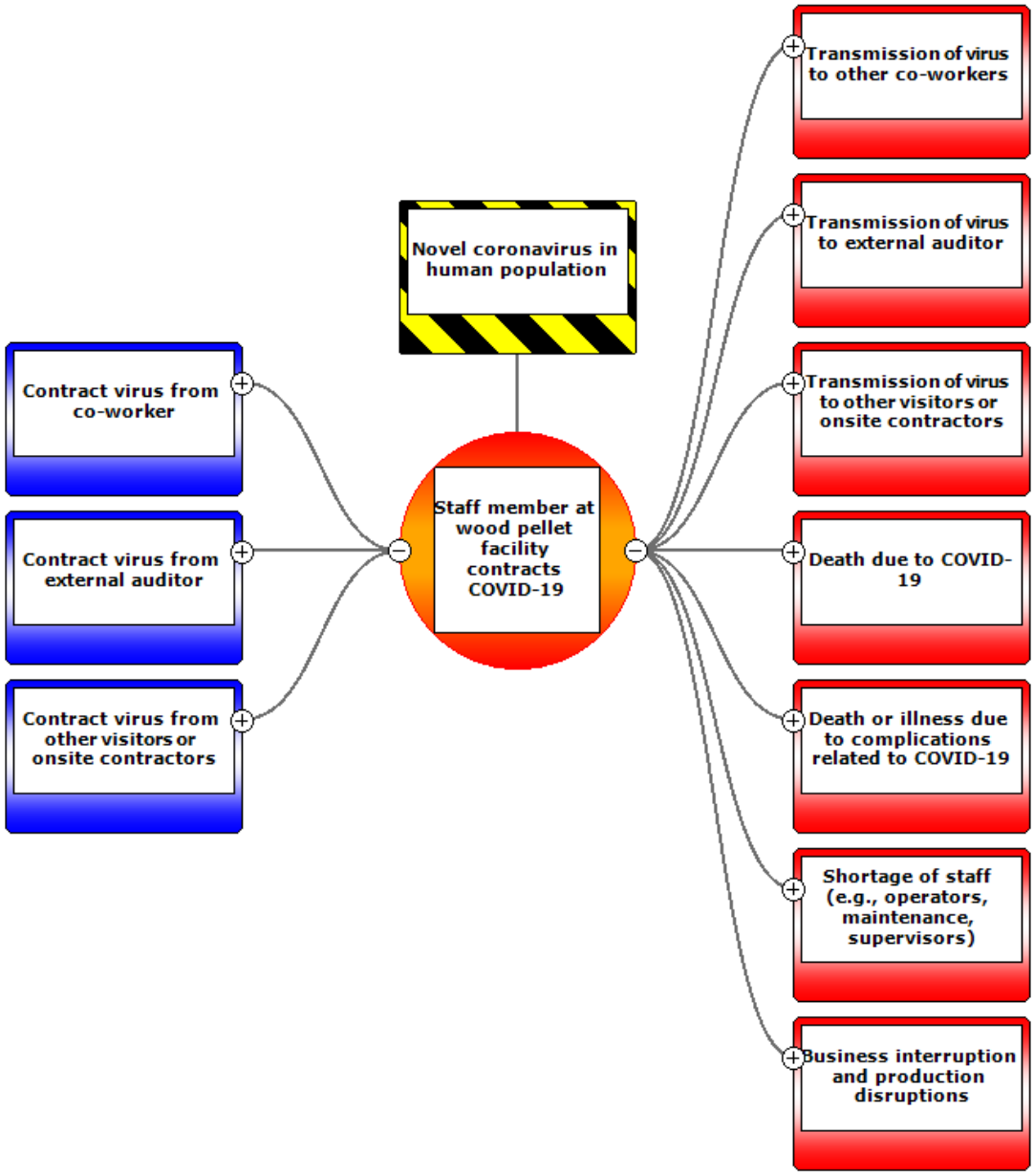

Figure 4-1. Excerpt of bow tie diagram representing a staff member at a BCFSC wood pellet facility contracting COVID-19

4.3 Barrier Evaluation

As previously discussed, the objectives of this research include evaluating prevention and mitigation measures currently in place, and exploring additional measures based on

inherently safer design (ISD) and the hierarchy of controls (HOC). This barrier evaluation methodology, as described in Chapter 3, was based on the ISD protocol for bow tie analysis (BTA) (Rayner Brown, Hastie, et al., 2021).

4.3.1 Barrier Categorization with Respect to the Hierarchy of Controls

To begin the barrier evaluation for the BCFSC bow tie diagram, the barriers were categorized with respect to the HOC. Table 4-1 provides the COVID-19 barriers identified for the BCFSC wood pellet facility bow tie diagram. Many of the barriers are both prevention and mitigation barriers, and therefore appear on both sides of the bow tie diagram. Many also appear in several threat and consequence lines. In Table 4-1, the barriers are organized in the order in which they first appear in the bow tie diagram, as read from top-left to bottom-right.

Table 4-1. BCFSC wood pellet facility COVID-19 barriers (categorized with respect to the HOC)

Barrier	Barrier Type
Install physical barriers where feasible when 2 m physical distance between workers is not possible (i.e., plastic partition, hanging tarp)	Passive Engineered
Vaccination for staff members who are vaccine-eligible	Passive Engineered
Work from home when feasible	Administrative (with aspects of ISD)
Work alone when feasible	Administrative (with aspects of ISD)
Assess whether task is critical; delay work within 2 m if task deemed not critical	Administrative (with aspects of ISD)
When feasible, limit duration of exposure/working within 2 m (i.e., less than 30 minutes)	Administrative (with aspects of ISD)
Work in pods; organize small groups of workers consistently working together (i.e., cohort)	Administrative (with aspects of ISD)
Stagger start times, stop times, and breaks to reduce congregation/congestion of workers	Administrative (with aspects of ISD)
Use only your own designated/dedicated tools when possible	Administrative (with aspects of ISD)

Barrier	Barrier Type
Complete pre-shift screening (e.g., temperature monitoring) and pre-task health assessment	Administrative (with aspects of ISD)
Complete healthy worker assessment, which might include not coming in contact with another person that has COVID-19 symptoms in the past 10 days	Administrative (with aspects of ISD)
COVID-19 testing of potential or symptomatic individuals to prevent transmission	Administrative (with aspects of ISD)
Supervisor oversight and sign-off on critical tasks. These higher risk activities may require additional monitoring during the task to minimize potential exposures	Administrative (with aspects of ISD)
More planning during pre-task activities to ensure that all tools and processes are well thought out to minimize the amount of time workers are in close proximity	Administrative (with aspects of ISD)
Assess whether meetings need to take place face-to-face; consider using alternative forms of meetings when feasible (i.e., teleconferencing, video meetings)	Administrative (with aspects of ISD)
Ensure there are hand washing or sanitization facilities available and close to the activity so that workers can wash hands prior to the activity	Administrative (with aspects of ISD)
Maintain 2 m of physical distance	Administrative (with aspects of ISD)
Cleaning and infection control practices (e.g., decontamination of equipment, cleaning of high-touch surface areas)	Administrative
Good hand hygiene and cough/sneeze etiquette (i.e., handwashing, avoid touching face, sneeze into elbow)	Administrative
Wear face mask or covering in common indoor areas of workplace unless there is a physical barrier between workers	Administrative
Consider wearing additional PPE (i.e., N95 Respirator, half mask respirator with current fit testing, shaved face and goggles, face shield with safety glasses, non-permeable gloves)	Administrative
Complete field level risk assessment (FLRA) form before performing work within 2 m	Administrative
Workplace COVID-19 education, training, and signage	Administrative
Assess whether external auditor must visit site; consider if audit can be completed using alternative forms of meetings when feasible (i.e., teleconferencing, video meetings)	Administrative (with aspects of ISD)
Minimize in-person/on-site document review during audits. Auditors can take pictures of documentation or receive most of the documentation for review prior to visiting site	Administrative (with aspects of ISD)

Barrier	Barrier Type
Only one external auditor permitted on-site at a time; minimize number of visitors	Administrative (with aspects of ISD)
Auditor should use their own office supplies	Administrative (with aspects of ISD)
Auditor should handle material (i.e., paper) with gloves, disinfect, and place in storage for 24 hours	Administrative (with aspects of ISD)
Screening questions for auditors; auditors should follow travel protocols (i.e., monitor health and exposures 14 days prior to visiting site)	Administrative (with aspects of ISD)
Auditor has a disinfection kit that can be used during travel and on-site audit activities (i.e., bottled water, dry towels, disinfection wipes or spray, masks, latex gloves, alcohol-based hand sanitizer, large and small Ziploc bags)	Administrative (with aspects of ISD)
Pre-arrange safe places for interviews; consider doing them outside when possible	Administrative (with aspects of ISD)
Auditor should not eat or drink with host personnel at any time and should only use their personal food, drink, and utensils	Administrative (with aspects of ISD)
Complete Site Pre-Visit Assessment for auditors	Administrative
Complete field level risk assessment (FLRA) form before performing audit activity	Administrative
Auditor must wear face-shield, or mask and eye protection, and impervious gloves in addition to the required site PPE. Other PPE considerations include N95 respirator, half mask respirator with current fit testing, shaved face and goggles, face shield with safety glasses, and non-permeable gloves	Administrative
Assess whether visit on-site is necessary	Administrative (with aspects of ISD)
Screening questions; visitors and contractors should follow travel protocols (i.e., monitor health and exposures 14 days prior to visiting onsite)	Administrative (with aspects of ISD)
Quarantine or isolate if confirmed positive case	Administrative (with aspects of ISD)
Auditor should immediately withdraw from site and contact BCFSC if there is any evidence of virus activity on-site or indications of infections on-site	Administrative (with aspects of ISD)
Hospitalization	Administrative
Cross-training for all positions at wood pellet facility	Administrative
Increase finished product inventories for short term (to fill orders)	Administrative
Strategic alliances to fill orders with product from other producers	Administrative

4.3.2 Evaluation of Degradation Factors

The next step was to categorize the degradation factors with respect to the common human and organizational (HOF) categories. As previously discussed, the common HOF categories of degradation factors are slips and lapses, mistakes, unintended violation, situational violations, organizational optimizing, personal optimizing, and recklessness (Rayner Brown, VanBerkel, et al., 2021). Table 4-2 provides the COVID-19 barriers identified for the wood pellet facility and the corresponding degradation factors that are related to HOF.

Table 4-2. BCFSC wood pellet facility COVID-19 barriers and corresponding degradation factors (categorized with respect to the HOF categories)

Barrier	Degradation Factor	Degradation Factor Category
Install physical barriers where feasible when 2 m physical distance between workers is not possible (i.e., plastic partition, hanging tarp)	Difficulty accommodating barrier in facility space; need to ensure barrier does not impede egress and safe working space	Organizational optimizing or situational violation
	Barrier could impede heating, ventilation, and air conditioning (HVAC) and airflow if not placed or designed properly	Situational violation or mistake
	Barrier materials could be difficult to obtain and/or expensive	Organizational optimizing
	Worker could go around barrier if not designed or placed properly; need to have good ergonomics	Personal optimizing, situational violation, or recklessness
	Barrier not maintained or installed properly, so it falls or has gaps	Organizational optimizing

Barrier	Degradation Factor	Degradation Factor Category
Vaccination for staff members who are vaccine-eligible	Vaccine hesitancy	Personal optimizing
	Vaccine is less effective if partially vaccinated, or if exposed to COVID-19 within 14 days of vaccination	Situational violation or unintended violation
	Resource limitations (e.g., staff or vaccine supply)	Situational violation
Assess whether task is critical; delay work within 2 m if task deemed not critical	Incorrect assessment (e.g., task deemed critical when it is not)	Unintended violation or mistake
When feasible, limit duration of exposure/working within 2 m (i.e., less than 30 minutes)	Acceptable time window for close contact could vary based on different factors (e.g., distance or transmissibility of virus)	Situational violation or unintended violation
Stagger start times, stop times, and breaks to reduce congregation/congestion of workers	Difficulty due to operational demands (i.e., need a certain number of people to be working at once)	Organizational optimizing
Use only your own designated/dedicated tools when possible	Limited workplace supply of tools	Organizational optimizing
Complete pre-shift screening (e.g., temperature monitoring) and pre-task health assessment	Worker could be asymptomatic or develop symptoms later in shift	Situational violation or unintended violation
Complete healthy worker assessment, which might include not coming in contact with another person that has COVID-19 symptoms in the past 10 days	Delay in knowing that worker was in close contact with someone who subsequently tested positive; delay in knowing of potential COVID-19 exposure	Situational violation or unintended violation
COVID-19 testing of potential or symptomatic individuals to prevent transmission	Widespread, rapid, asymptomatic COVID-19 testing (i.e., pop-up centres like Nova Scotia) unavailable or low testing capabilities	Situational violation
	Worker may not have been instructed to self-isolate while waiting for test results	Unintended violation or mistake

Barrier	Degradation Factor	Degradation Factor Category
Supervisor oversight and sign-off on critical tasks. These higher risk activities may require additional monitoring during the task to minimize potential exposures	Supervisors are busy and carry most of the responsibilities of activities; difficulty dedicating extra time for review due to operational demands	Organizational optimizing or situational violation
	Complacency	Personal optimizing
More planning during pre-task activities to ensure that all tools and processes are well thought out to minimize the amount of time workers are in close proximity	Difficulty dedicating extra time for review due to operational demands, or if tasks are time sensitive	Organizational optimizing or situational violation
	No extra time for review during emergencies	Situational violation
Ensure there are hand washing or sanitization facilities available and close to the activity so that workers can wash hands prior to the activity	Cold weather (seasonal) reduces feasibility of temporary hand washing stations	Situational violation
	Hand washing station runs out of supplies (i.e., water, soap, towels)	Situational violation
	Limited facility spacing and difficulty finding a safe location for hand washing station	Situational violation
Maintain 2 m of physical distance	Difficulty maintaining 2 m physical distance during maintenance activities	Situational violation
	Difficulty judging 2 m distance	Unintended violation or mistake
Cleaning and infection control practices (e.g., decontamination of equipment, cleaning of high-touch surface areas)	Run out of cleaning supplies	Situational violation
Good hand hygiene and cough/sneeze etiquette (i.e., handwashing, avoid touching face, sneeze into elbow)	Proper hand hygiene method not followed	Unintended violation, mistake, situational violation, or personal optimizing
Wear face mask or covering in common indoor areas of workplace unless there is a physical barrier between workers	Face mask worn improperly	Unintended violation, mistake, situational violation, or personal optimizing

Barrier	Degradation Factor	Degradation Factor Category
Consider wearing additional PPE (i.e., N95 Respirator, half mask respirator with current fit testing, shaved face and goggles, face shield with safety glasses, non-permeable gloves)	Run out of PPE supplies	Situational violation
	PPE is different or out of the norm; confusion of when to wear or how to wear	Unintended violation or mistake
	Fit test expired, or worker was never fit tested	Situational violation
	Personnel do not want to wear PPE (i.e., uncomfortable, makes task more difficult)	Personal optimizing
Completion of field level risk assessment (FLRA) form before performing work within 2 m	Difficulty dedicating extra time for review due to operational demands, or if tasks are time sensitive	Organizational optimizing or situational violation
	Criteria for judging task criticality is subjective; no criteria listed in guidelines	Unintended violation or mistake
Workplace COVID-19 education, training, and signage	Difficulty revising documents/signage based on changes to guidelines and case numbers	Unintended violation
	Signage becomes damaged in manufacturing environment	Unintended violation or situational violation
	Difficulty performing training in timely manner with limited number of people in meetings	Situational violation or organizational optimizing
Assess whether external auditor must visit site; consider if audit can be completed using alternative forms of meetings when feasible (i.e., teleconferencing, video meetings)	Criteria for judging audit criticality is subjective; no criteria listed in guidelines	Unintended violation or mistake
	Technological challenges associated with teleconferencing (i.e., internet connection), or out of date equipment for teleconferencing	Situational violation

Barrier	Degradation Factor	Degradation Factor Category
Minimize in-person/on-site document review during audits. Auditors can take pictures of documentation or receive most of the documentation for review prior to visiting site	Difficulty planning and managing time to send documentation ahead of audit, or communicating to personnel what documentation is required for audit	Organizational optimizing or situational violation
Only one external auditor permitted on-site at a time; minimize number of visitors	Difficulty coordinating and arranging audits with operation demands if a number of audits must be completed	Organizational optimizing
	More than one audit scheduled at once; accident; miscommunication	Unintended violation or mistake
	Difficulty rescheduling audit due to on-site infection activity	Situational violation
Auditor should use their own office supplies	Difficulty bringing/traveling with office supplies; auditor runs out of office supplies	Personal optimizing or situational violation
Auditor should handle material (i.e., paper) with gloves, disinfect, and place in storage for 24 hours	Not followed because auditor forgot, or auditor urgently needs to look at document	Unintended violation, organizational optimizing, situational violation, or slip or lapse
Screening questions for auditors; auditors should follow travel protocols (i.e., monitor health and exposures 14 days prior to visiting site)	Auditor could be asymptomatic or develop symptoms later in visit	Unintended violation
	Auditor not honest about travel history or symptoms	Personal optimizing or recklessness
Auditor has a disinfection kit that can be used during travel and on-site audit activities (i.e., bottled water, dry towels, disinfection wipes or spray, masks, latex gloves, alcohol-based hand sanitizer, large and small Ziploc bags)	Disinfection kit runs out of supplies	Unintended violation
	Difficulty bringing/traveling with disinfection kit	Personal optimizing

Barrier	Degradation Factor	Degradation Factor Category
Pre-arrange safe places for interviews; consider doing them outside when possible	Difficulty performing interviews outside due to weather conditions	Situational violation
	Difficulty finding extra space for interviews	Situational violation
	Available space is limited by equipment needed to perform interview (i.e., electricity, seat, desk)	Situational violation
Auditor should not eat or drink with host personnel at any time and should only use their personal food, drink, and utensils	Limited areas in facility that are safe for eating	Situational violation
	Difficulty bringing/traveling with personal food, drink, and utensils	Personal optimizing
Complete Site Pre-Visit Assessment for auditors	Auditor not honest about travel history or symptoms	Personal optimizing or recklessness
Complete field level risk assessment (FLRA) form before performing audit activity	Difficulty dedicating extra time for review due to operational demands, or if tasks are time sensitive	Organizational optimizing or situational violation
	Criteria for judging task criticality is subjective; no criteria listed in guidelines	Unintended violation or mistake
Auditor must wear face-shield, or mask and eye protection, and impervious gloves in addition to the required site PPE. Other PPE considerations include N95 respirator, half mask respirator with current fit testing, shaved face and goggles, face shield with safety glasses, and non-permeable gloves	Run out of PPE supplies	Situational violation
	PPE is different or out of the norm; confusion of when to wear or how to wear	Unintended violation or mistake
	Fit test expired or if someone was never fit tested and they need to be fit tested now	Situational violation
	Personnel do not want to wear PPE (i.e., uncomfortable, makes task more difficult)	Personal optimizing
Screening questions; visitors and contractors should follow travel protocols (i.e., monitor health and exposures 14 days prior to visiting onsite)	Visitor/contractor could be asymptomatic or develop symptoms later in visit	Unintended violation
	Visitor/contractor is not honest about travel history or symptoms	Personal optimizing or recklessness

Barrier	Degradation Factor	Degradation Factor Category
Quarantine or isolate if confirmed positive case	Quarantine/isolation guidelines not followed because it is difficult for individuals to quarantine or isolate by themselves; misunderstanding of guidelines; lack of support to take time off work; guidelines not followed deliberately	Personal optimizing, unintended violation, mistake, or recklessness
Auditor should immediately withdraw from site and contact BCFSC if there is any evidence of virus activity on-site or indications of infections on-site	Difficulty detecting virus activity or infections without widespread testing	Situational violation
Hospitalization	Resource/bed shortages	Situational violation
	Individual does not get to hospital in time due to a very sudden onset of serious symptoms	Unintended violation
	Individual cannot afford ambulance fees	Situational violation
	Individual does not go to hospital because they do not have support or childcare at home, not able to leave to go to hospital; individual may think they are not that sick	Personal optimizing, unintended violation, or mistake

In the province of Nova Scotia, pop-up testing sites offer on-site rapid antigen testing (also called point-of-care testing) services and take-home rapid antigen testing kits. Testing is available to all ages and no screening or assessment is required, but supply is based on availability so testing kits are limited to one per person. The pop-up sites visit areas across the province that have limited access to COVID-19 testing or that have an increased rate of COVID-19 cases (Nova Scotia Health, n.d.).

4.3.3 Evaluation of Degradation Factor Controls

The next step in the barrier evaluation was to evaluate the degradation factor controls. Similar to the barriers, these were categorized with respect to the HOC. Table 4-3 provides the COVID-19 barrier degradation factors and the corresponding degradation factor controls.

Table 4-3. BCFSC wood pellet facility COVID-19 barrier degradation factors and corresponding degradation factor controls (categorized with respect to the HOC)

Degradation Factor	Degradation Factor Control	Degradation Factor Control Category
Difficulty accommodating barrier in facility space; need to ensure barrier does not impede egress and safe working space	Identify and select the appropriate type of barrier for application, if feasible, for space	ISD (simplification)
Barrier could impede heating, ventilation, and air conditioning (HVAC) and airflow if not placed or designed properly	Consult an HVAC specialist to ensure that HVAC is running properly and is balanced correctly for the space	Administrative
Barrier materials could be difficult to obtain and/or expensive	Supply chain management	Administrative
Worker could go around barrier if not designed or placed properly; need to have good ergonomics	Identify and select the appropriate type of barrier for application, if feasible, for space	ISD (simplification)
Barrier not maintained or installed properly, so it falls or has gaps	Use a robust design with right materials for application that would be easy to maintain and will not fall easily	ISD (simplification)

Degradation Factor	Degradation Factor Control	Degradation Factor Control Category
Vaccine hesitancy	Education and outreach (e.g., advertising, social media campaigns)	Administrative
	Target under-immunized sub-groups with tailored interventions (MacDonald & Dubé, 2018)	Administrative
	Host vaccine clinic on-site	Administrative (with aspects of ISD)
	Allow workers time off to get vaccinated	Administrative
	Remind patients by text, email, or mail as appropriate (MacDonald & Dubé, 2018)	Administrative
Vaccine is less effective if partially vaccinated, or if exposed to COVID-19 within 14 days of vaccination	Follow protocols and public health guidelines	Administrative
Resource limitations (e.g., staff or vaccine supply)	Support from other groups (i.e., military, Red Cross)	Administrative
Incorrect assessment (e.g., task deemed critical when it is not)	Education, training	Administrative
	Auditing	Administrative
Acceptable time window for close contact could vary based on different factors (e.g., distance or transmissibility of virus)	Minimize close contact as much as possible in all circumstances	Administrative (with aspects of ISD)
Difficulty due to operational demands (i.e., need a certain number of people to be working at once)	Management of change	Administrative
	Workers allowed to take breaks/lunch at their own discretion	Administrative
	Workers allowed to take lunch in cars	Administrative (with aspects of ISD)
Limited workplace supply of tools	If feasible, purchase more tools	Administrative
Worker could be asymptomatic or develop symptoms later in shift	Workers self-monitor for COVID-19 symptoms and follow all protocols	Administrative
	Facilitate the process for workers to report if they are feeling unwell	Administrative (with aspects of ISD)

Degradation Factor	Degradation Factor Control	Degradation Factor Control Category
Delay in knowing that worker was in close contact with someone who subsequently tested positive; delay in knowing of potential COVID-19 exposure	Workers self-monitor for COVID-19 symptoms and follow all protocols	Administrative
Widespread, rapid, asymptomatic COVID-19 testing (i.e., pop-up centres like Nova Scotia) unavailable or low testing capabilities	Point-of-care diagnostic testing for remote, rural, and Indigenous communities (BCCDC, 2021)	Administrative (with aspects of ISD)
Worker may not have been instructed to self-isolate while waiting for test results	Workers follow COVID-19 protocols and guidelines	Administrative
Supervisors are busy and carry most of the responsibilities of activities; difficulty dedicating extra time for review due to operational demands	Leadership support and strong COVID-19 safety culture to hold supervisors to high standards	Administrative
	Management of change	Administrative
Complacency	Leadership support and strong COVID-19 safety culture to hold supervisors to high standards	Administrative
	Audits	Administrative
Difficulty dedicating extra time for review due to operational demands, or if tasks are time sensitive	Management of change	Administrative
	Leadership support and strong COVID-19 safety culture to emphasize importance of this	Administrative
	Process is mainly automatic	Administrative
Cold weather (seasonal) reduces feasibility of temporary hand washing stations	Install hand washing stations inside facility	Administrative
	Strategically install hand sanitizer stations indoors	Administrative (with aspects of ISD)
Hand washing station runs out of supplies (i.e., water, soap, towels)	Use hand sanitizer as a back-up	Administrative (with aspects of ISD)
	Supply chain management	Administrative

Degradation Factor	Degradation Factor Control	Degradation Factor Control Category
Limited facility spacing and difficulty finding a safe location for hand washing station	Strategically install hand sanitizer stations indoors	Administrative (with aspects of ISD)
Difficulty maintaining 2 m physical distance during maintenance activities	Workers wear face masks and follow other protocols	Administrative
Difficulty judging 2 m distance	Floor or ground markings	Administrative (with aspects of ISD)
	Use common measurement aids (i.e., length of a 2-person couch, height of a fridge, etc.)	Administrative (with aspects of ISD)
Run out of cleaning supplies	Supply chain management	Administrative
Proper hand hygiene method not followed	Education, training	Administrative
Face mask worn improperly	Education	Administrative
Must remove mask when eating and drinking	Workers follow other protocols and guidelines	Administrative
Run out of PPE supplies	Supply chain management	Administrative
PPE is different or out of the norm; confusion of when to wear or how to wear	Education and training	Administrative
Fit test expired, or worker was never fit tested	Fit test program management	Administrative
Personnel do not want to wear PPE (i.e., uncomfortable, makes task more difficult)	Optimize PPE and use high-quality PPE that is more comfortable to wear and more suitable for tasks	Administrative (with aspects of ISD)
Difficulty dedicating extra time for review due to operational demands, or if tasks are time sensitive	Management of change	Administrative
	Leadership support and strong COVID-19 safety culture to emphasize importance of this	Administrative
Criteria for judging task criticality is subjective; no criteria listed in guidelines	Education, training	Administrative
Difficulty revising documents/signage based on changes to guidelines and case numbers	Management of change	Administrative

Degradation Factor	Degradation Factor Control	Degradation Factor Control Category
Signage becomes damaged in manufacturing environment	Use communication tools that are rugged and place them in appropriate locations	Administrative (with aspects of ISD)
Difficulty performing training in timely manner with limited number of people in meetings with limited number of people at once in meeting	Use virtual meetings and emails to communicate important information	Administrative (with aspects of ISD)
	Provide one-on-one education & training	Administrative
Technological challenges associated with teleconferencing (i.e., internet connection), or out of date equipment for teleconferencing	If feasible, buy up-to-date teleconference equipment and install	Administrative (with aspects of ISD)
Difficulty planning and managing time to send documentation ahead of audit, or communicating to personnel what documentation is required for audit	Project management	Administrative
Difficulty coordinating and arranging audits with operation demands if a number of audits must be completed	Project management	Administrative
Auditor not honest about travel history or symptoms	Code of ethics signed by auditors	Administrative
	Auditor could not be allowed to perform future audits	Administrative
Difficulty performing interviews outside due to weather conditions	If interviews must be completed indoors, ensure HVAC/ventilation is sufficient; open window	Passive Engineered
	Follow other protocols and guidelines	Administrative
Available space is limited by equipment needed to perform interview (i.e., electricity, seat, desk)	If interview must be completed indoors, ensure HVAC/ventilation is sufficient; open window	Passive Engineered

Degradation Factor	Degradation Factor Control	Degradation Factor Control Category
Limited areas in facility that are safe for eating	Follow other protocols and guidelines	Administrative
Visitor/contractor could be asymptomatic or develop symptoms later in visit	Visitors/contractors self-monitor for COVID-19 symptoms and follow all protocols	Administrative
	Facilitate process for visitors/contractors to report if they are feeling unwell	Administrative (with aspects of ISD)
Quarantine/isolation guidelines not followed because it is difficult for individuals to quarantine or isolate by themselves; misunderstanding of guidelines; lack of support to take time off work; guidelines not followed deliberately	Education and enforcement of quarantine/isolation guidelines	Administrative
	Support from government, workplace, friends, and family	Administrative
Difficulty detecting virus activity or infections without widespread testing	Point-of-care diagnostic testing for remote, rural, and Indigenous communities (BCCDC, 2021)	Administrative (with aspects of ISD)
Resource/bed shortages	Support from other groups (i.e., military, Red Cross)	Administrative
	Eliminate or postpone non-essential services	Administrative (with aspects of ISD)
	Share resources with other jurisdictions, travel (i.e., nurses, medical supplies)	Administrative
	Use triage and prioritize patients	Administrative
Individual cannot afford ambulance fees	Waive ambulance fee for COVID-19 patients (Gorman, 2021)	Administrative (with aspects of ISD)

In May 2021, the Nova Scotia government waived ambulance fees for people in COVID-related emergencies. This decision, made during the province's third wave of COVID-19,

followed reports that several people did not call for help due to concerns about the cost; the ambulance fee for Nova Scotians with a valid health card is $146.55 (Gorman, 2021).

The BCCDC provides guidance for using point-of-care testing (also known as rapid testing) to "assist with the diagnosis of symptomatic individuals within rural, remote, First Nations and Indigenous communities in B.C. where laboratory-based diagnostic testing is not readily available" (BCCDC, 2021). This guidance recognizes that remote, rural, First Nations and Indigenous communities experience challenges and barriers in accessing laboratory-based testing and care (BCCDC, 2021).

4.4 Results and Discussion

Almost all the COVID-19 barriers identified in this bow tie diagram were administrative, and many of these administrative barriers were identified to have aspects of ISD. As described in Chapter 1, it should be noted that although the barriers incorporate ISD principles, they are still administrative. For the barriers that were administrative (with aspects of ISD), most were rooted in the strategy of minimization, and some were rooted in the strategies of simplification, moderation, and substitution. There were two passive engineered barriers, and none of the identified barriers were active engineered or ISD. Due to the research team's understanding that many COVID-19 barriers rely on human behaviour (Rayner Brown, VanBerkel, et al., 2021), it was expected that most of the barriers identified in this bow tie diagram would be categorized as administrative. These results show the importance of considering HOF in bow tie diagrams for COVID-19 scenarios, and the benefit of using an ISD mindset (Rayner Brown, VanBerkel, et al., 2021) to incorporate the ISD principles and concepts into barriers of other levels in the HOC (like administrative controls).

Of the identified degradation factors that were related to human behaviour and HOF, the most common category was situational violation. The next most common category was unintended violation, followed by personal optimizing, mistakes, organizational optimizing, recklessness, and slips or lapses. Situational violations can be described as "I cannot get the job done if I follow the rules, but I did the job anyway" (CCPS/EI, 2018). With this category as the most common, it could be understood that many degradation factors in this bow tie diagram are the result of the COVID-19 barriers being inconvenient, or the result of situations that are out of the staff members' control. Additionally, wood pellet facility staff members may be unaware that their actions are degrading the effectiveness of the barriers. These results show the importance of communicating how the COVID-19 barriers fit into the routines of staff members and how these barriers can fail, and the benefit of working to make the COVID-19 barriers as convenient as possible.

Most of the degradation factor controls identified in this bow tie were categorized as administrative, and many of these administrative controls were identified to have aspects of ISD. As with the barriers, it was expected that most of the degradation factor controls would be categorized as administrative or administrative (with aspects of ISD). This also seems reasonable given that many of the degradation factors were related to human behaviour and HOF. Two of the degradation factor controls were identified as passive engineered and three of the degradation factor controls were identified as ISD, adhering to the strategy of simplification. These ISD degradation factor controls demonstrate overcoming the degradation factors by helping to make the barriers more robust.

4.5 Recommendations

As described in Section 4.2, the development of this bow tie diagram included recommended barriers and degradation factor controls from the provincial governments of Nova Scotia and British Columbia. These recommendations are listed in the following table, Table 4-4. It should be noted that these measures may be in place in the BCFSC wood pellet facilities, but they were not identified in the BCFSC COVID-19 resources available at the time of the workshop.

Table 4-4. Additional COVID-19 barriers/degradation factor controls that could be considered by the BCFSC wood pellet facility (categorized with respect to the HOC)

Control	Control Type	Reference
Waive ambulance fee for COVID-19 patients (Gorman, 2021)	Administrative (with aspects of ISD)	(Gorman, 2021)
Pop-up testing centres like in Nova Scotia	Administrative (with aspects of ISD)	
Point-of-care diagnostic testing for remote, rural, and Indigenous communities	Administrative (with aspects of ISD)	(BCCDC, 2021)

Chapter 5 Chemical Process Industry Barriers

This chapter describes the research performed regarding COVID-19 safety measures in the chemical process industry (CPI). It provides details of the research scope; the identification of barriers, degradation factors, and degradation factor controls; the evaluation of the barriers, degradation factors, and degradation factor controls; and the results and conclusions of this research.

5.1 Scope

Even though a bow tie diagram was not prepared, the scope of this analysis was similarly defined by the hazard and top event. As with the bow tie diagrams described in Chapters 3 and 4, the hazard was "Novel coronavirus in human population" (Rayner Brown, VanBerkel, et al., 2021). Identified through the Dalhousie research team's CPI network, the Bluewater Association for Safety, Environment, and Sustainability (BASES) facilitates the exchange of information in the Sarnia-Lambton area of Ontario to protect workers, the public, and the environment. BASES is supported by the members of three organizations: the Sarnia-Lambton Community Awareness and Emergency Response (CAER), the Sarnia-Lambton Industrial Educational Cooperative (IEC), and the Sarnia-Lambton Environmental Association (SLEA) (BASES, n.d.-b). The BASES Member Directory (BASES, n.d.-a) currently lists 26 members, including several companies in the Sarnia refining and petrochemical sectors (BASES, n.d.-c). A search into the publicly available online COVID-19 resources of BASES members in the Sarnia-Lambton Petrochemical and Refining Complex (Sarnia-Lambton Economic Partnership, n.d.) revealed many Suncor COVID-19 guidelines and protocols. Therefore, the top event was defined as "Staff member at Suncor refinery in Sarnia, Ontario contracts COVID-19".

5.2 Barrier Identification and Evaluation

The COVID-19 barriers in place at the Suncor refinery in Sarnia, Ontario, were identified through the publicly available online Suncor COVID-19 resources, including guidelines and protocols. The corresponding degradation factors and degradation factor controls were identified using the same online resources, degradation factors and controls for common barriers (Rayner Brown, VanBerkel, et al., 2021), and knowledge previously accumulated during this research.

The objectives of this research include evaluating prevention and mitigation measures currently in place, and exploring additional measures based on inherently safer design (ISD) and the hierarchy of controls (HOC). As before, this barrier evaluation methodology was based on the ISD protocol for bow tie analysis (BTA) (Rayner Brown, Hastie, et al., 2021). The first step is to examine and categorize the barriers with respect to the HOC. The next step is to evaluate the degradation factors and degradation controls (Rayner Brown, Hastie, et al., 2021).

5.2.1 Barrier Categorization with Respect to the Hierarchy of Controls

To begin the barrier evaluation for the identified COVID-19 barriers, the barriers were categorized with respect to the HOC. Table 5-1 provides the COVID-19 barriers identified for the Suncor refinery in Sarnia. Many of the barriers, if presented in a bow tie diagram, would be both prevention and mitigation barriers and would, therefore, appear on both sides of the bow tie diagram.

Table 5-1. Sarnia refinery COVID-19 barriers (categorized with respect to the HOC)

Barrier	Categorization	Reference
Staff complete pre-access self assessment prior to reporting to site	Administrative (with aspects of ISD)	(Suncor, n.d.-a) (Suncor, 2020d)
Transition staff levels to essential personnel only at all operations and offices (until further notice) *Note: essential means "those who absolutely need to be there to do their job and keep critical operations running safely and reliably"	Administrative (with aspects of ISD)	(Suncor, n.d.-b)
Additional screening measures and compulsory self-isolation measure for employees who have traveled outside of their country of residence or been exposed to confirmed COVID-19 cases	Administrative (with aspects of ISD)	(Suncor, n.d.-b)
Increased cleaning and sanitization protocols	Administrative	(Suncor, n.d.-b)
Staff members participate in temperature screening at site	Administrative	(Suncor, n.d.-b) (Suncor, 2020e)
Wherever possible, maintain physical distancing of 2 m (6 ft) between workers	Administrative (with aspects of ISD)	(Suncor, 2020c) (Suncor, 2020b)
Hold meetings via Teams/Skype or telephone instead of in-person	ISD (Substitution)	(Suncor, 2020c)
Practice good hand hygiene and sneeze/cough etiquette	Administrative	(Suncor, 2020c)
Wherever possible, avoid face-to-face engagements with other workers	Administrative (with aspects of ISD)	(Suncor, 2020c)
Wherever possible, avoid prolonged contact with others	Administrative (with aspects of ISD)	(Suncor, 2020c)
Wherever possible, ensure greetings are touchless	Administrative (with aspects of ISD)	(Suncor, 2020c)
Wherever possible, implement measures to limit contact during meals and breaks	Administrative (with aspects of ISD)	(Suncor, 2020c)

Barrier	Categorization	Reference
Limit mass gatherings per guidance from regional health authority	Administrative (with aspects of ISD)	(Suncor, 2020c)
Contractors conduct pre-access self assessment prior to reporting to site	Administrative (with aspects of ISD)	(Suncor, 2020a)
Contractors participate in temperature screening at site	Administrative	(Suncor, 2020a)
Contractors report symptomatic or confirmed COVID-19 positive test results and close contact with a confirmed COVID-19 case	Administrative	(Suncor, 2020a)

5.2.2 Evaluation of Degradation Factors

The next step was to evaluate the degradation factors. As previously discussed, in the context of the COVID-19 pandemic, many degradation factors are related to human behaviour and human and organizational factors (HOF). The common HOF categories of degradation factors are slips and lapses, mistakes, unintended violation, situational violations, organizational optimizing, personal optimizing, and recklessness (Rayner Brown, VanBerkel, et al., 2021). Table 5-2 provides the COVID-19 barriers identified for the Suncor refinery in Sarnia and the corresponding degradation factors that are related to HOF.

Table 5-2. Sarnia refinery COVID-19 barriers and corresponding degradation factors (categorized with respect to the HOF categories)

Barrier	Degradation Factor	HOF Category	Reference
Staff complete pre-access self assessment prior to reporting to site	Worker is asymptomatic	Situational violation	(Suncor, n.d.-a) (Suncor, 2020d)
	Worker not honest about travel history or symptoms	Personal optimizing	

Barrier	Degradation Factor	HOF Category	Reference
Transition staff levels to essential personnel only at all operations and offices (until further notice)	Remote access connection issues	Situational violation	(Suncor, n.d.-b)
Additional screening measures and compulsory self-isolation measure for employees who have traveled outside of their country of residence or been exposed to confirmed COVID-19 cases	Worker not honest about travel history or exposure history	Personal optimizing	(Suncor, n.d.-b)
Increased cleaning and sanitization protocols	Proper cleaning procedure not followed	Unintended violation, mistake, situational violation, or organizational optimizing	(Suncor, n.d.-b)
Staff members participate in temperature screening at site	Worker is asymptomatic	Situational violation	(Suncor, n.d.-b) (Suncor, 2020e)
	Proper temperature screening procedure not followed	Unintended violation, mistake, situational violation, or organizational optimizing	(Suncor, n.d.-b) (Suncor, 2020e)
Wherever possible, physical distancing of 2 m (6 ft) between workers	Physical distancing between workers not possible	Situational violation	(Suncor, 2020c) (Suncor, 2020b)
	Physical distancing not followed	Unintended violation, mistake, or personal optimizing	(Rayner Brown, VanBerkel, et al., 2021)
Hold meetings via Teams/Skype or telephone instead of in-person	Remote access connection issues	Situational violation	(Suncor, 2020c)

Barrier	Degradation Factor	HOF Category	Reference
Practice good hand hygiene and sneeze/cough etiquette	Proper hand washing procedure not followed	Unintended violation, mistake, situational violation, or personal optimizing	(Suncor, 2020c)
Limit mass gatherings per guidance from regional health authority	Regional health authority guidance not followed	Unintended violation, mistake, situational violation, or organizational optimizing	(Suncor, 2020c)
Contractors conduct pre-access self assessment prior to reporting to site	Contractor not honest about travel history or symptoms	Personal optimizing	(Suncor, 2020a)

5.2.3 Evaluation of degradation factor controls

The next step in the barrier evaluation was to evaluate the degradation factor controls. Similar to the barriers, these were categorized with respect to the HOC. Table 5-3 provides the COVID-19 barrier degradation factors and the corresponding degradation factor controls identified for the Suncor refinery in Sarnia.

Table 5-3. Sarnia refinery COVID-19 barrier degradation factors and corresponding degradation factor controls (categorized with respect to the HOC)

Degradation Factor	Degradation Factor Control	Degradation Factor Control Type	Reference
Proper cleaning procedure not followed	Education, training	Administrative	(Suncor, n.d.-b)
Proper temperature screening procedure not followed	Education, training	Administrative	(Suncor, n.d.-b) (Suncor, 2020e)
Physical distancing between workers not possible	Adjust work plan to include Physical Distancing Requirements (e.g.,	Administrative (with aspects of ISD)	(Suncor, 2020c) (Suncor, 2020b)

	one worker instead of two)		
	Apply physical barriers (e.g., plexiglass, cubicles, welding curtains)	Passive Engineered	(Suncor, 2020c) (Suncor, 2020b)
	Plan work to minimize time and number of workers required	Administrative (with aspects of ISD)	(Suncor, 2020b)
	Adjust working conditions or worker positions so that workers are not face-to-face	Administrative (with aspects of ISD)	(Suncor, 2020b)
	Use PPE along with other controls wherever possible	Administrative	(Suncor, 2020b)
Physical distancing not followed	Education	Administrative	(Rayner Brown, VanBerkel, et al., 2021)
	Visual cues and signage	Administrative (with aspects of ISD)	(Rayner Brown, VanBerkel, et al., 2021)
Proper hand washing procedure not followed	Education, training	Administrative	(Suncor, 2020c)
Degradation Factor	**Degradation Factor Control**	**Degradation Factor Control Type**	**Reference**
Regional health authority guidance not followed	Education, training	Administrative	(Suncor, 2020c)
	Signage	Administrative (with aspects of ISD)	(Rayner Brown, VanBerkel, et al., 2021)

5.3 Results and Discussion

Almost all the COVID-19 barriers identified in this bow tie analysis were administrative, and many of these administrative barriers were identified to have aspects of ISD. The

barriers that were administrative (with aspects of ISD) were rooted in the principles of minimization and moderation; since the hazard (novel coronavirus in human population) cannot be eliminated, these administrative barriers incorporate minimization by aiming to minimize the number of people on-site, and they incorporate moderation through the limitation of effects (transmission of COVID-19). There was one ISD barrier, adhering to the principle of substitution, and none of the identified barriers were passive engineered or active engineered. It should be noted that, when employing the principle of substitution, the risks associated with the substitution must be identified and assessed. For example, substituting in-person meetings for teleconferencing and allowing staff introduces new challenges relate to remote access. As previously discussed, it was expected that most of the barriers identified would be categorized as administrative (Rayner Brown, VanBerkel, et al., 2021). These results show the importance of considering HOF in COVID-19 bow tie analysis, and the benefit of incorporating the ISD principles and concepts into barriers of other levels in the HOC (like administrative controls) using an ISD mindset (Rayner Brown, VanBerkel, et al., 2021).

Of the identified degradation factors that were related to human behaviour and HOF, the most common category was situational violation. The next most common categories were unintended violation, mistakes, personal optimizing, and organizational optimizing. None of the identified degradation factors were categorized as recklessness or slips or lapses. Situational violations can be described as “I cannot get the job done if I follow the rules, but I did the job anyway” (CCPS/EI, 2018). With this category as the most common, it could be understood that many degradation factors identified are the result of the COVID-19 barriers being inconvenient, or the result of situations that are out of the refinery staff

members' control. These results show the importance of communicating how the COVID-19 barriers fit into the routines of refinery staff members and how these barriers can fail, and the benefit of working to make the COVID-19 barriers as convenient as possible.

Most of the degradation factor controls identified in this bow tie analysis were categorized as administrative, and many of these administrative controls were identified to have aspects of ISD. As with the barriers, it was expected that most of the degradation factor controls would be categorized as administrative or administrative (with aspects of ISD). This also makes sense given that many of the degradation factors were related to human behaviour and HOF. One of the degradation factor controls was identified as passive engineered, and none were identified as ISD or active engineered.

Chapter 6 Bow Tie Communication Tools

This chapter describes the communication tools based on the bow tie diagram developed in collaboration with the IWK. The IWK bow tie diagram is described in Chapter 3 of this thesis document. The current chapter provides the detailed objectives and development of two communication tools: one for IWK leadership and executives, and one for frontline IWK team members.

6.1 Communication Tool Objectives

As there is a need for effective communication of risk reduction measures during a pandemic, an objective of this research is to develop ways to disseminate the results. The IWK Infection Prevention and Control (IPAC) team expressed interest in producing communication tools for different stakeholders from the bow tie diagram that was developed.

One communication tool that was developed is a document for IWK executives and leadership. The objectives of this document are to introduce the bow tie methodology and its potential uses at the IWK health centre and demonstrate the success of the COVID-19 barriers that were implemented. This document may also be summarized by the IPAC team in a presentation aimed at senior leaders responsible for IWK policy decisions. It is being developed in collaboration with a science communications specialist and a graphic designer.

The other communication tool that was developed is a one-page document or poster for frontline IWK team members, similar to the Center for Chemical Process Safety (CCPS) Process Safety Beacon. The Process Safety Beacon is a one-page monthly newsletter that

aims to deliver process safety messages to manufacturing personnel such as plant operators (CCPS, n.d.). It is also intended to include photographs or other graphics so that it will draw attention if posted on a bulletin board. To fit this format, the Beacon cannot be more than about 300 words (Kletz & Amyotte, 2019). Each Beacon presents a real-life incident, describes the lessons learned from the incident investigation, and details practical means to prevent the occurrence of a similar incident at the reader's plant (CCPS, n.d.). Frontline workers are the target audience for the Beacon, and it focuses on suggested actions that frontline workers can do within the scope of their jobs. While managers and other technical staff may read the Beacon, it is not written for them (Kletz & Amyotte, 2019). The objective of this document is to communicate to frontline IWK team members the effectiveness of the health centre's COVID-19 barriers and why they were implemented.

6.2 Communication Tool Development

Communication tools were first discussed as a potential product of the IWK COVID-19 bow tie diagram during the first bow tie workshop in April 2021. Following this first bow tie workshop, researchers from Dalhousie University, including the current author, met with one of the IWK continuous improvement specialists to further discuss the communication tools. Using a Capture-Create-Channels matrix developed by K. Rayner Brown (personal communication, April 21, 2021), which is included in Appendix C, the two target audiences were identified: IWK leadership and executives, and IWK frontline team members. This matrix also helped identify the aforementioned objectives for the two communication tools.

Next, researchers from Dalhousie University, including the current author, met with a science communications specialist to discuss employing their services to develop the

communication tools. This meeting helped identify the type of tools (i.e., multi-page document, poster, presentation) that could meet the objectives.

A summary document was developed and distributed to the science communications specialist and the IWK continuous improvement specialist. This summary document included an introduction to bow tie analysis, a review of previous applications of bow ties as communication tools, an introduction to the CCPS Process Safety Beacon, and the objectives of the IWK bow tie communication tools. Following the distribution of this document, the current author met with the science communications specialist and the IWK continuous improvement specialist to discuss the formal development of the communication tools. The next step was for the science communications specialist to interview the current author and the IWK continuous improvement specialist; this interview was held virtually on January 5, 2022.

Following the interview, the science communications specialist developed the document for IWK executives and leadership. After review and revision by the current author, the document was sent to the graphic designer. The graphic designer drafted and revised the document based on comments from the current author and the Dalhousie research team. This document for IWK executives and leadership is included as Appendix D. The four-page document introduces the bow tie methodology and the bow tie diagram elements, discusses a previous application of bow ties in healthcare, discusses the current research and collaboration with the IWK Health Centre, summarizes a threat line ("Contract virus from asymptomatic patient"), and discusses some potential next steps of this research and collaboration. The threat "Contract virus from asymptomatic patient" was highlighted in this document as the current author thought it to be the threat that best showed the

robustness of the COVID-19 safety measures implemented at the IWK Health Centre by the IPAC team. Additionally, as this document is intended for leadership and executives, detailed information on the research collaboration and research funding is included.

The science communications specialist developed the first draft of the one-page document, or poster, for frontline IWK team members by trimming down the four-page document. Next, the current author reviewed and revised the draft to ensure the required technical content was included and that the format included elements of the Process Safety Beacon (i.e., action items for frontline workers). Following the review and revision by the current author, the document was sent to the graphic designer. Like the four-page document, the graphic designer drafted and revised the document based on comments from the current author and the Dalhousie research team. This one-page document, or poster, for frontline IWK team members is included as Appendix E. This document briefly introduces the bow tie methodology and the bow tie diagram elements, summarizes the current research and collaboration, provides an excerpt of the IWK Health Centre COVID-19 bow tie diagram, and lists some barriers and degradation factor controls that are related to frontline team member behaviour and actions. Following the Beacon format, this document is about 300 words long, includes eye-catching graphics and images (like smaller bow tie diagrams), and includes barriers and degradation factor controls as action items that the IWK frontline team members can consider within the scope of their work.

Chapter 7 Conclusions and Future Work

In conclusion, bow tie analysis (BTA) has been applied to conduct comprehensive hazard analysis of the threat of contracting COVID-19 for three receptor groups of interest: patient or family member at the IWK Health Centre in acute care, staff member at a British Columbia Forest Safety Council (BCFSC) wood pellet facility, and staff member at the Suncor refinery in Sarnia, Ontario. An inherently safer design (ISD) protocol for process hazard analysis (Rayner Brown, Hastie, et al., 2021) was used as a guide for evaluation of the identified COVID-19 barriers, and additional COVID-19 controls have been recommended. Furthermore, two communication tools were developed from the IWK bow tie diagram to effectively disseminate the findings of this research to two target audiences: IWK leadership and executives, and IWK frontline team members.

Following the bow tie methodology, likely threats that could lead to a patient or family member at the IWK Health Centre in acute care, or staff member at a BCFSC wood pellet facility receptor groups contracting COVID-19 were identified. These threats described contracting the virus from other groups at these locations including team/staff members, patients, auditors, visitors, and external contractors.

Using a barrier evaluation methodology based on the ISD protocol for BTA (Rayner Brown, Hastie, et al., 2021), the current prevention and mitigation measures for the three receptor groups of interest were evaluated. This evaluation provided the following lessons learned:

- Most of the COVID-19 barriers identified were administrative, and many of these administrative barriers were determined to have aspects of ISD. If the hazard itself

cannot be directly minimized (or eliminated), substituted, moderated, or simplified, the controls that remain are passive engineered, active engineered, and, primarily, administrative safety. It is important to use an ISD mindset (Rayner Brown, VanBerkel, et al., 2021) to incorporate the ISD principles into controls of other levels in the HOC (like administrative controls). It is also important to note that, although they have aspects of ISD, administrative controls such as physical distancing are easily defeated and are the least effective type of control.

- Most of the COVID-19 degradation factors identified were related to human behaviour and human and organization factors (HOF); it is important to consider HOF in BTA for COVID-19 scenarios. The most common HOF category was situational violation, which can be described as "I cannot get the job done if I follow the rules, but I did the job anyway" (CCPS/EI, 2018). It is important to communicate how the COVID-19 barriers fit into the routines of staff members and how these barriers can fail, and to make COVID-19 barriers as convenient as possible.
- Like the barriers, most of the COVID-19 degradation factor controls identified were administrative, and many of these administrative controls were determined to have aspects of ISD. It is important to note that, for degradation factors related to human behaviour and HOF, the corresponding degradation factor controls are usually administrative.

Additional COVID-19 prevention and mitigation measures based on ISD and the HOC were identified for the patient or family member at the IWK Health Centre in acute care or a staff member at a BCFSC wood pellet facility receptor groups. These additional measures

were identified using recommended industry resources, provincial health resources, and the lived experiences of the researchers. While these measures may be in place at these facilities, it is important to note them so that they are recorded and can be considered for the COVID-19 pandemic or future respiratory illness pandemics.

Two communication tools were developed from the IWK bow tie diagram: a four-page document for IWK leadership and executives and a one-page document, or poster, for IWK frontline team members. It is important to note that the information included in a communication tool, and the presentation of that information, must be adjusted to fit the communication needs of the intended audience. For example, the document for IWK leadership and executives included a summary of the barriers, degradation factors, and degradation factor controls in place to prevent the threat of contracting COVID-19 from an asymptomatic patient, while the document for IWK frontline workers highlighted barriers and degradation factor controls that are within the scope of their work.

By identifying and presenting COVID-19 barriers, degradation factors, and degradation factor controls, this research has developed additional example-based guidance that can be used for the COVID-19 pandemic or future respiratory illness pandemics. Furthermore, this research presents a methodology for evaluating the effectiveness of barriers. This provides guidance for making risk-based decisions regarding the selection of the most effective COVID-19 safety measures.

Research is currently being performed by Dalhousie researchers to quantify bow tie diagrams and/or the bow tie methodology. This research is using the bow tie diagram developed in collaboration with the IWK as a case study.

One recommendation for future work is the application of BTA to additional non-chemical process industries (CPI). The current research, in addition to studies such as those summarized in Section 2.1, demonstrates successful application of the bow tie methodology to analyze a non-CPI hazard (contracting COVID-19) in non-CPI facilities (health centre and wood pellet facility). BTA could be a valuable hazard analysis tool for a variety of industries; however, further research is needed to identify and understand the challenges related to introducing BTA in different industries, and to develop example-based guidance for these industry applications.

Another recommendation for future work is the consideration and incorporation of ISD principles in other levels of the HOC. This research has demonstrated, and highlighted the importance of, using an ISD mindset to incorporate ISD principles in administrative controls. However, administrative safety is only one of the other levels of the HOC; how might the ISD principles might be incorporated in passive and active engineered controls? Further research could explore, and develop example-based guidance of, passive and active engineered safety controls with aspects of ISD.

A final recommendation for future work is further consideration and incorporation of human behaviour and HOF in BTA. The current research demonstrated the importance of considering human behaviour and HOF in BTA for COVID-19 scenarios. Additionally, as stated in Section 1.7, degradation factors in the categories of recklessness, slips and lapses, and mistakes are difficult to treat in bow tie diagrams, so they are generally not identified during bow tie workshops (CCPS/EI, 2018). Further research could explore best practices for incorporating human behaviour and HOF in bow tie diagrams, explore the challenges

related to treating HOF degradation factors in bow tie diagrams, and provide guidance for considering human behaviour and HOF in BTA.

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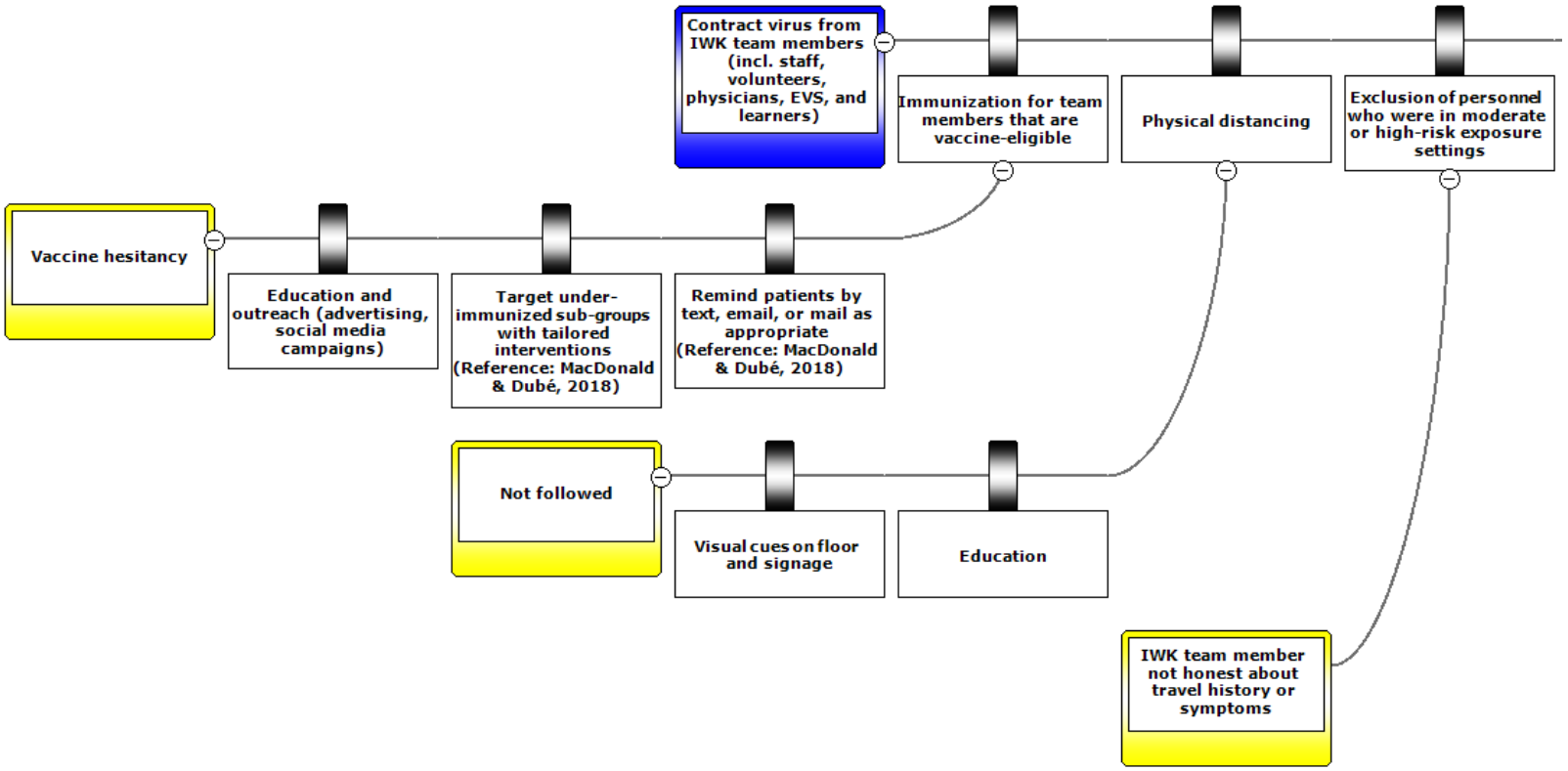
Appendix A IWK Health Centre Bow Tie Diagram



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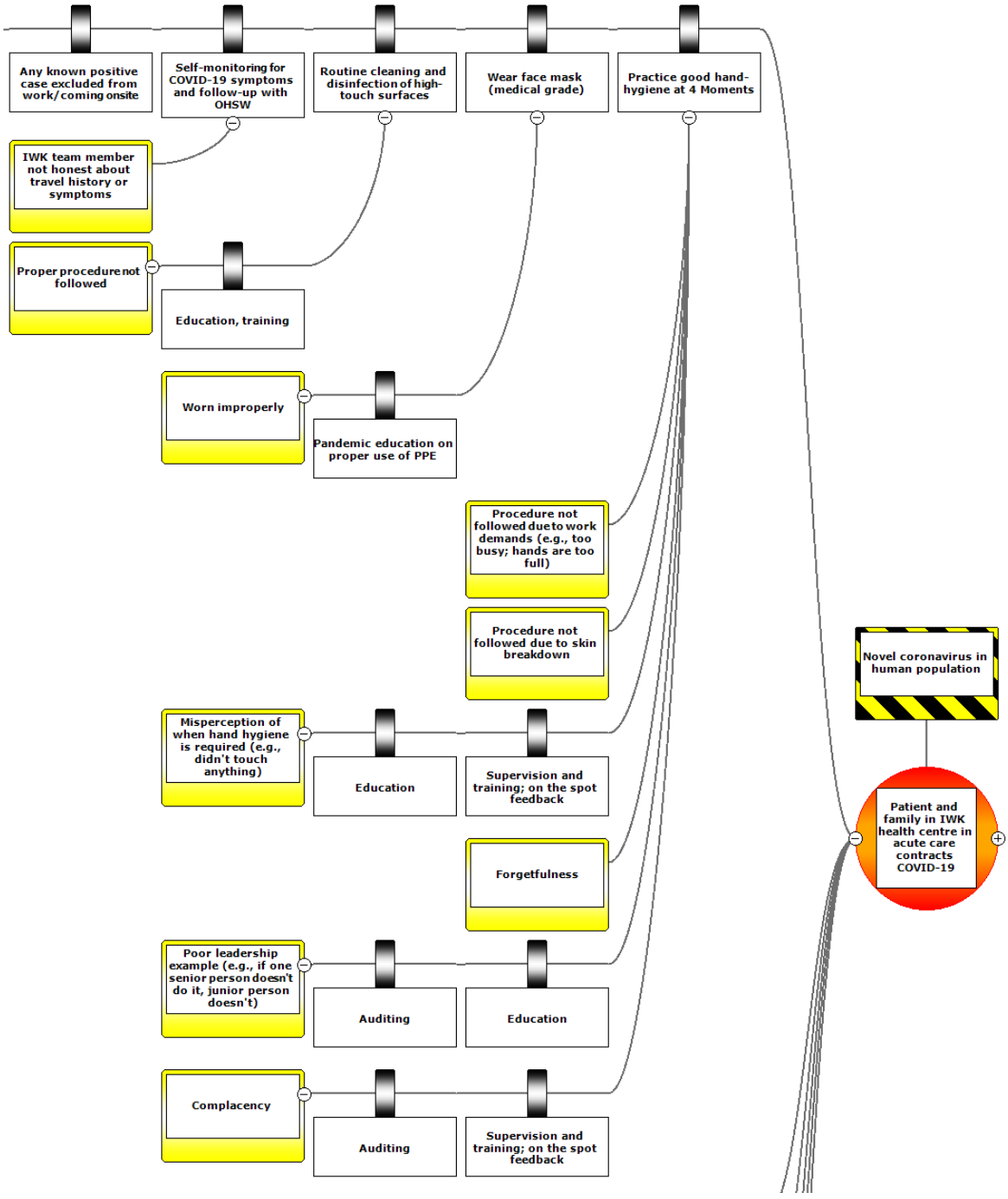

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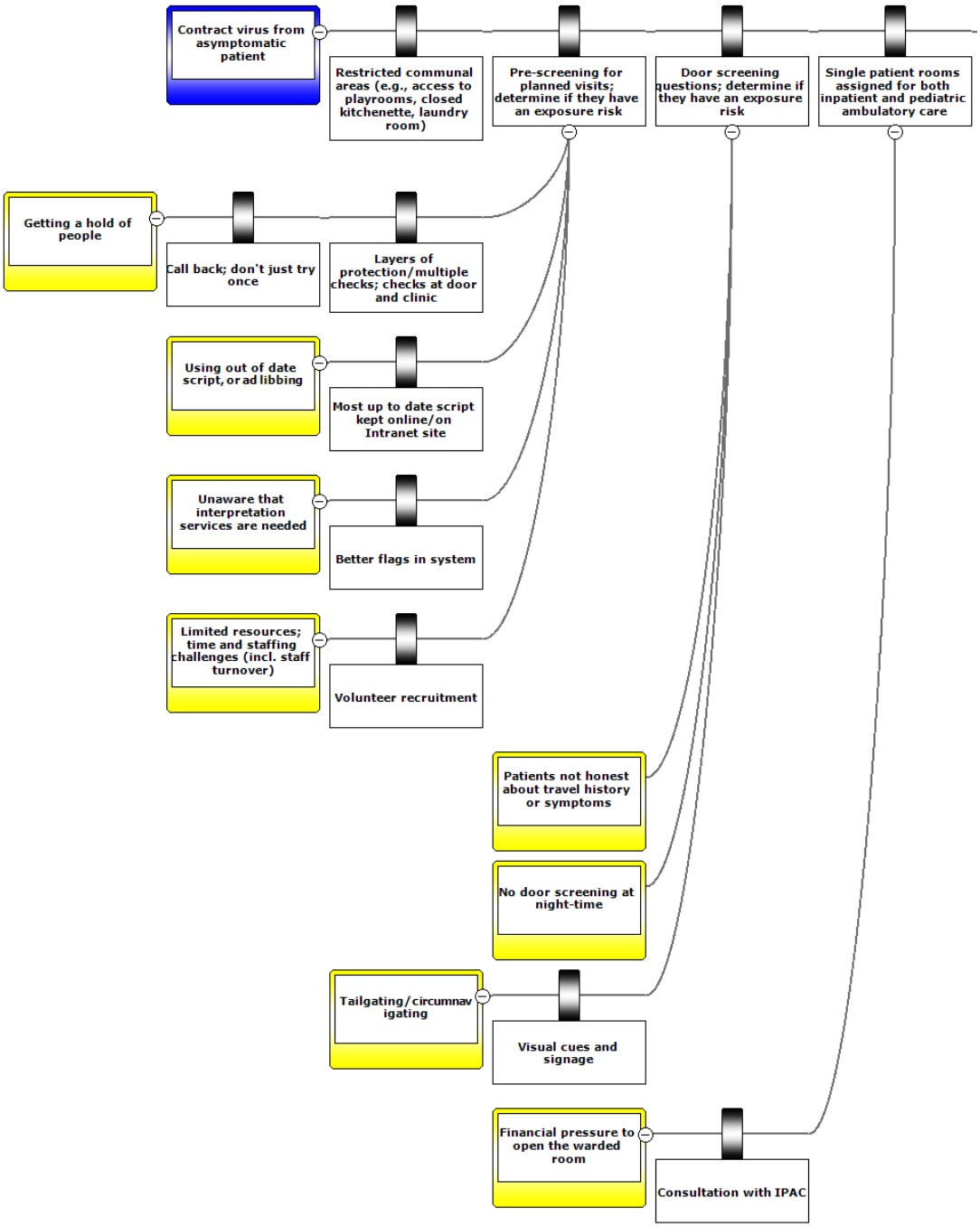

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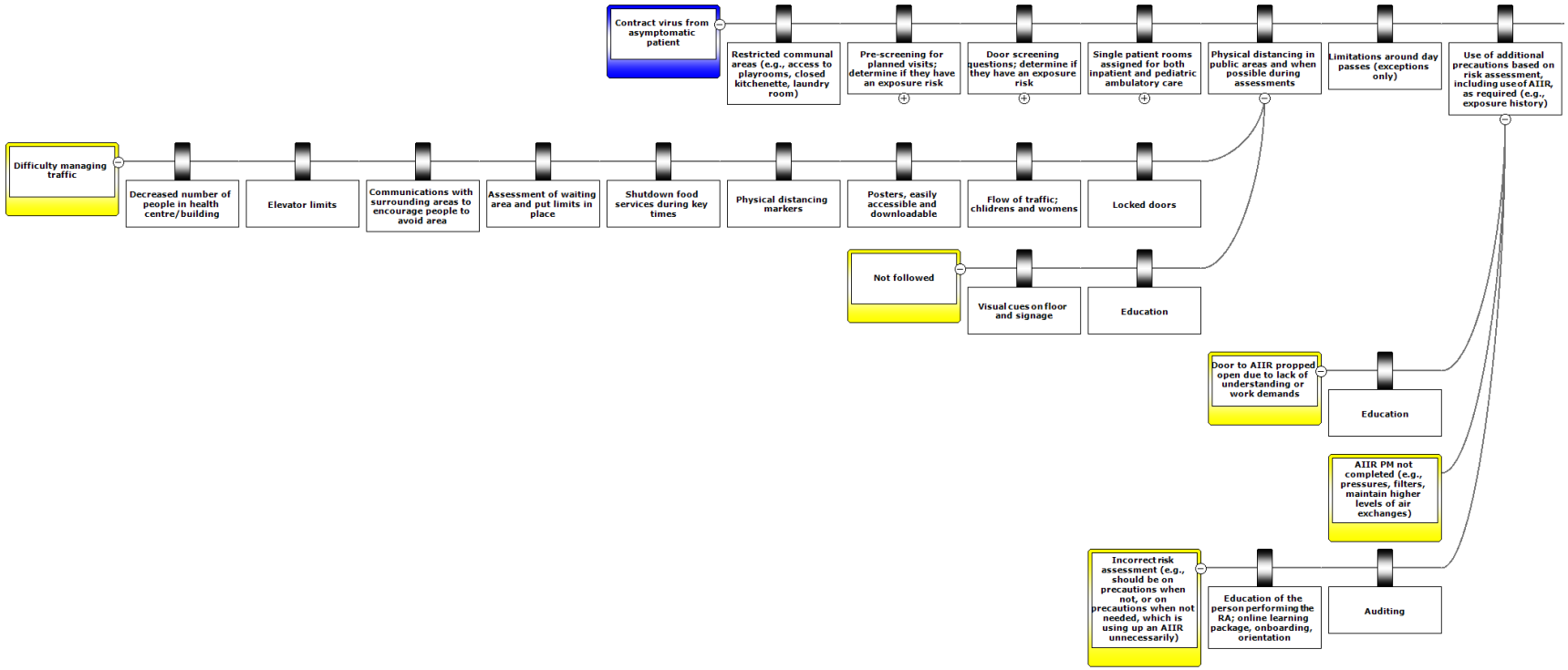

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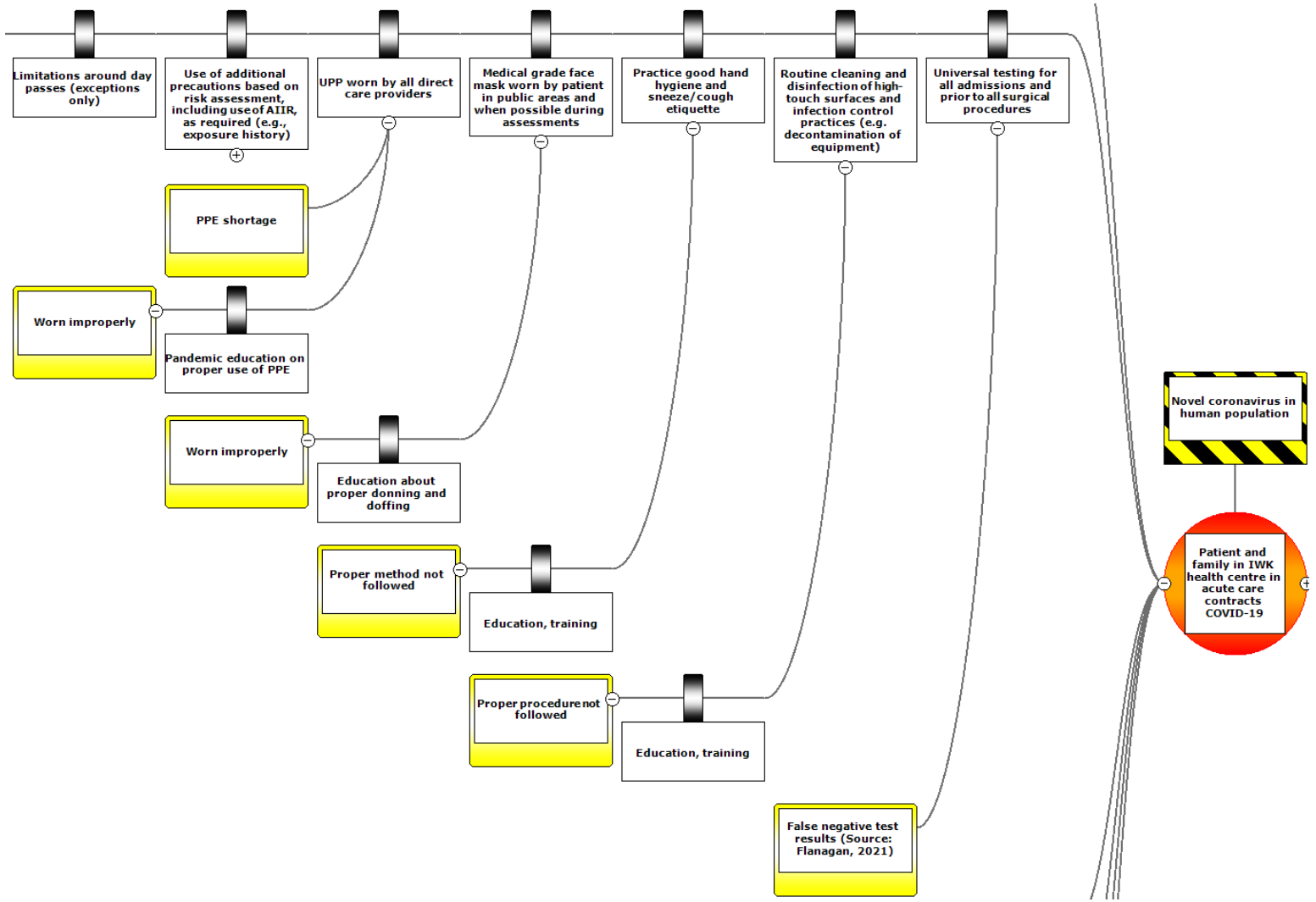

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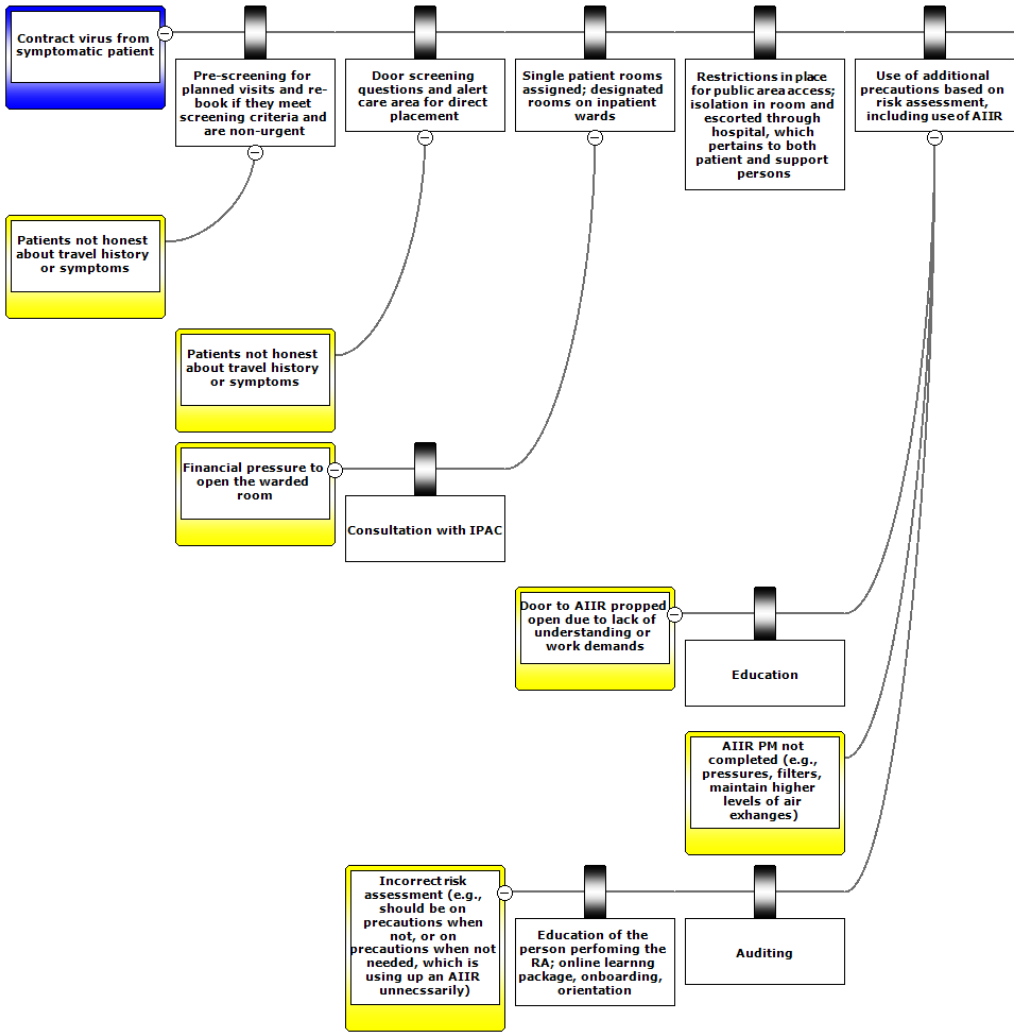

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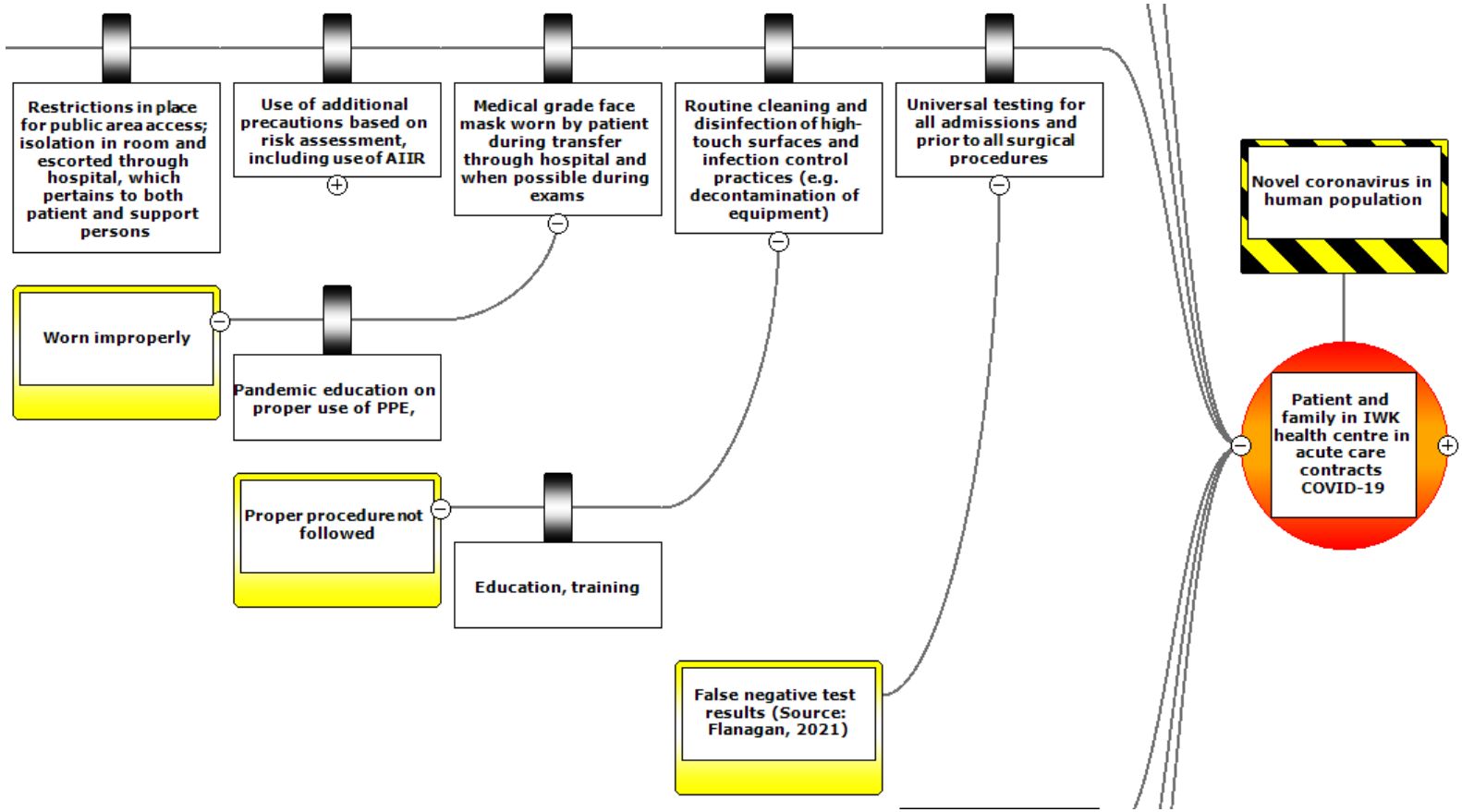

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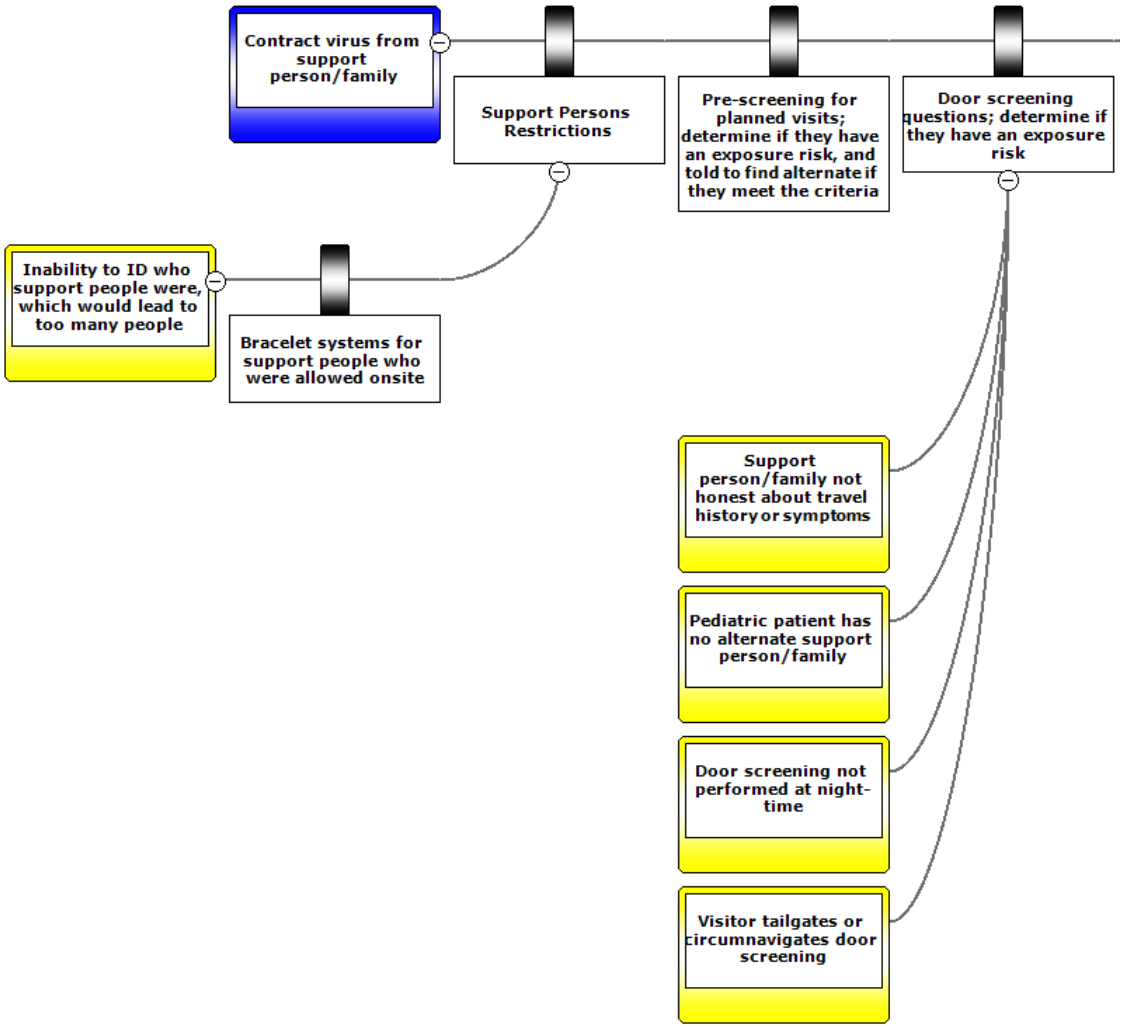

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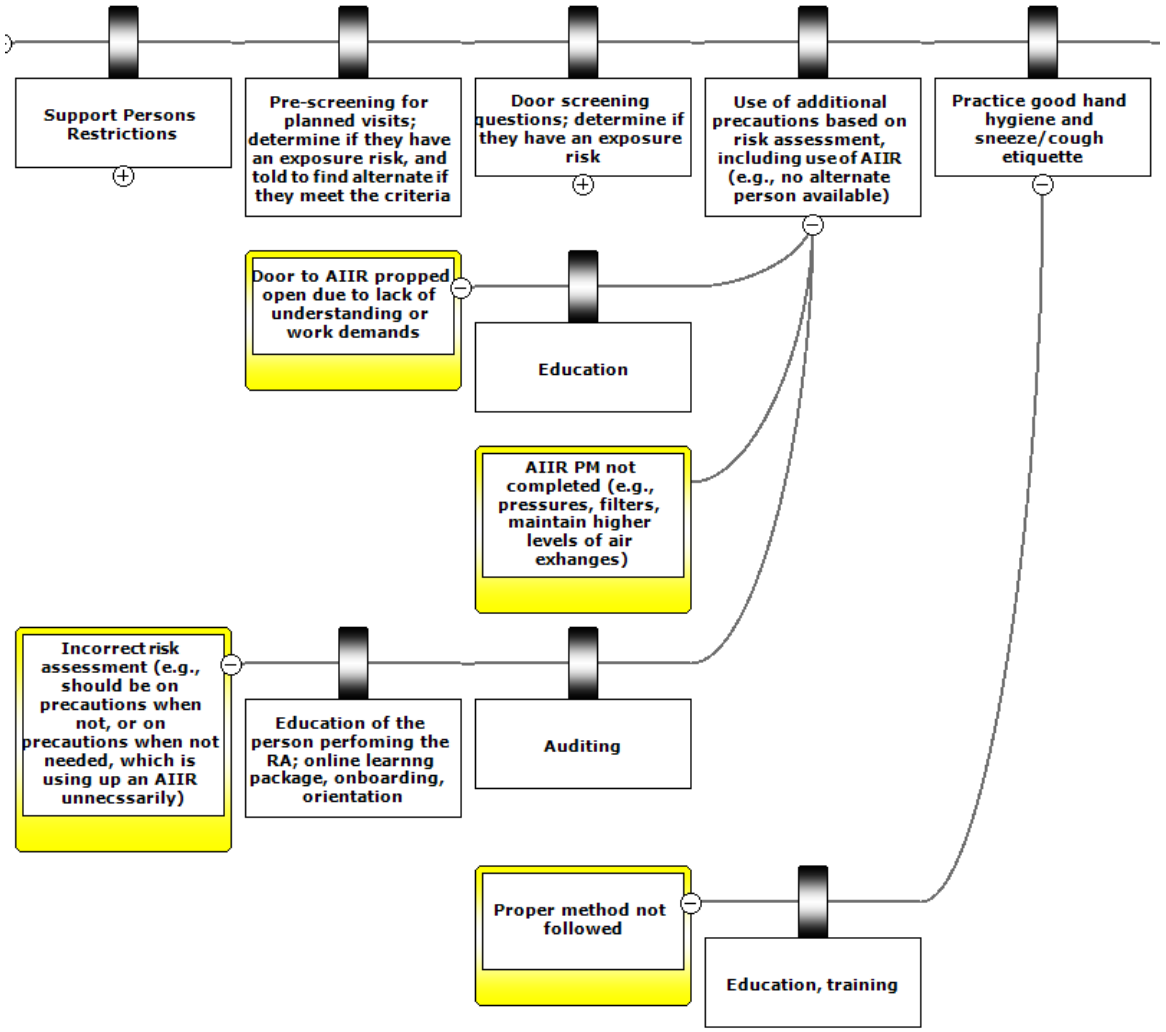

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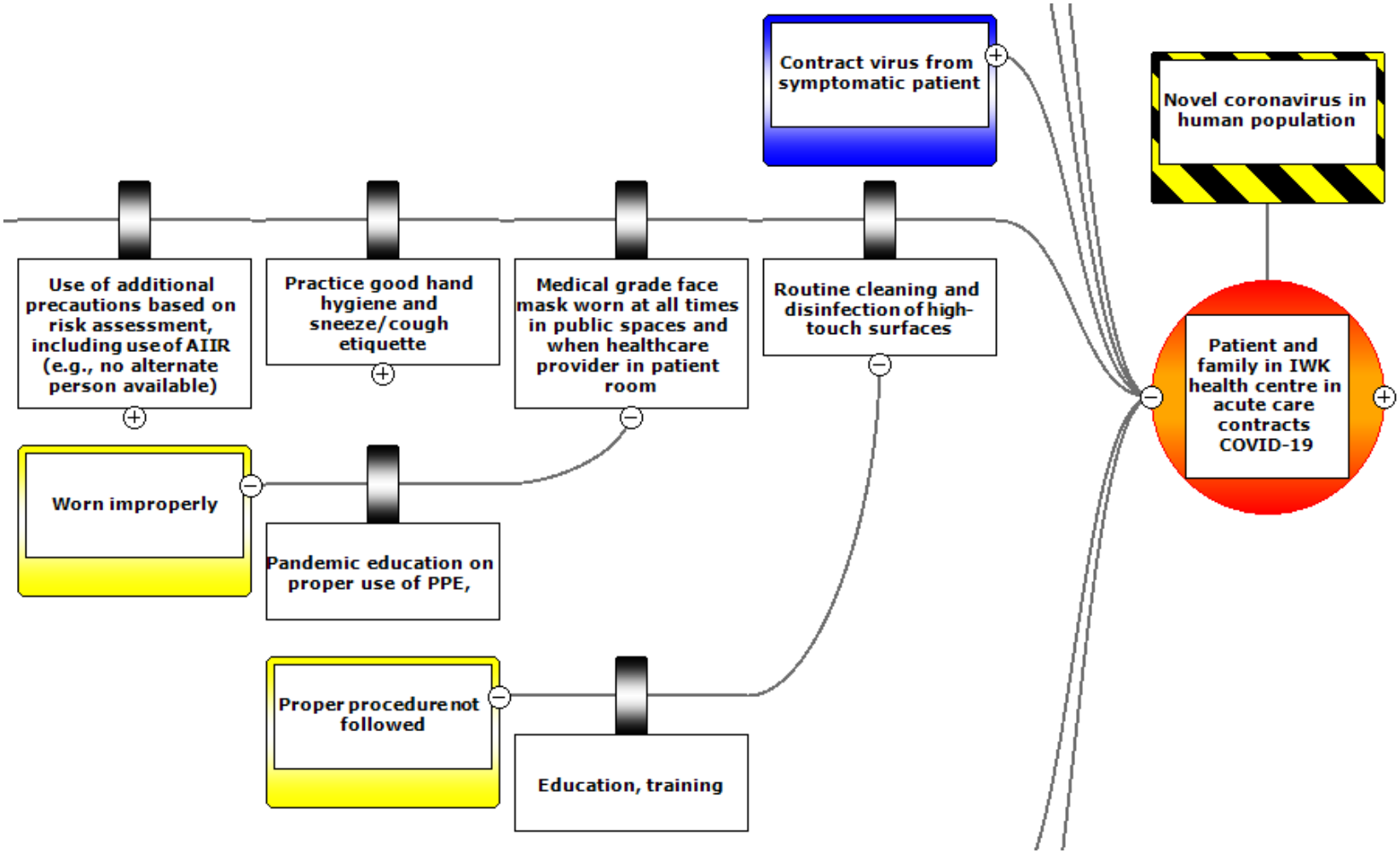

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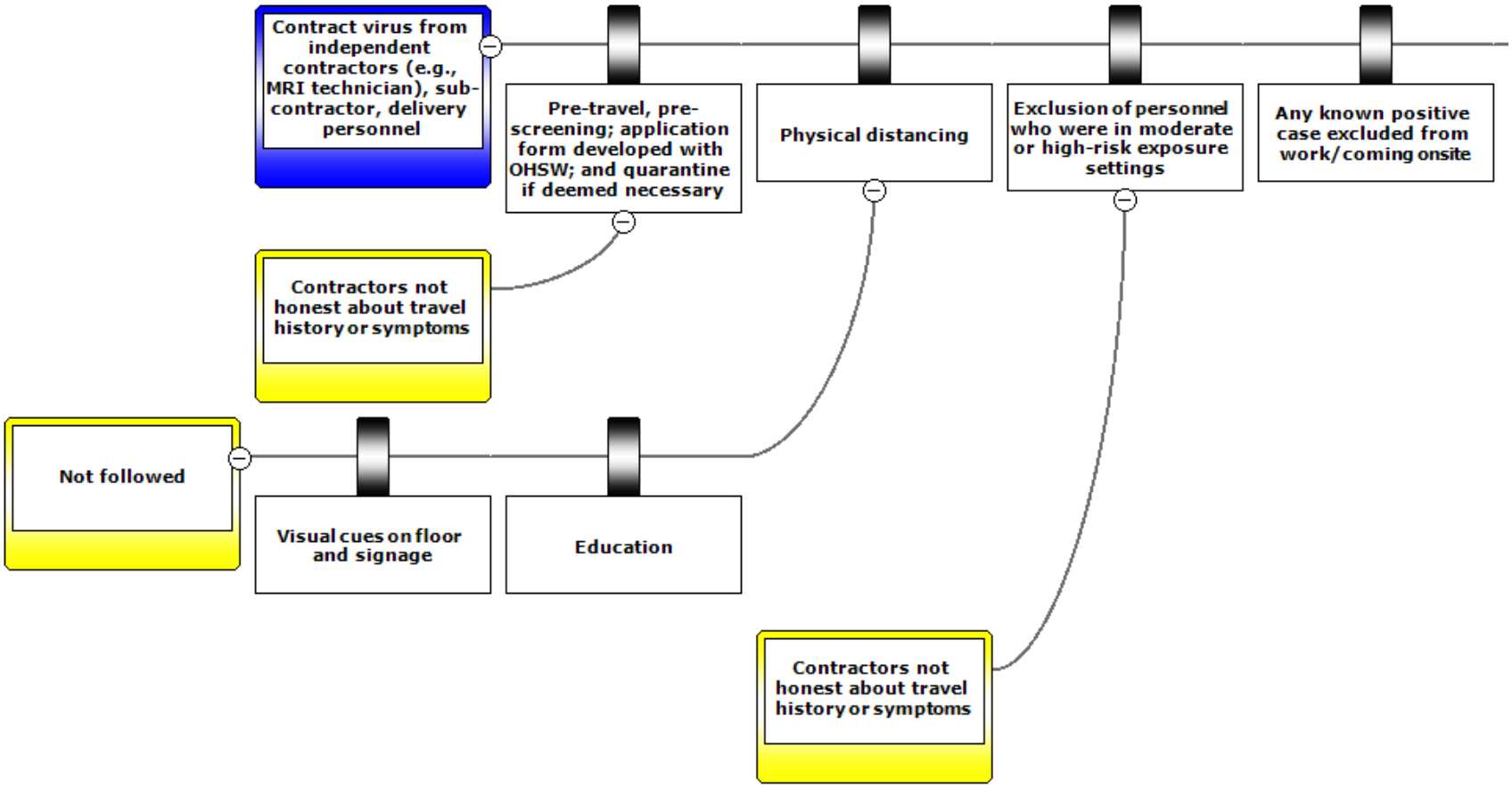

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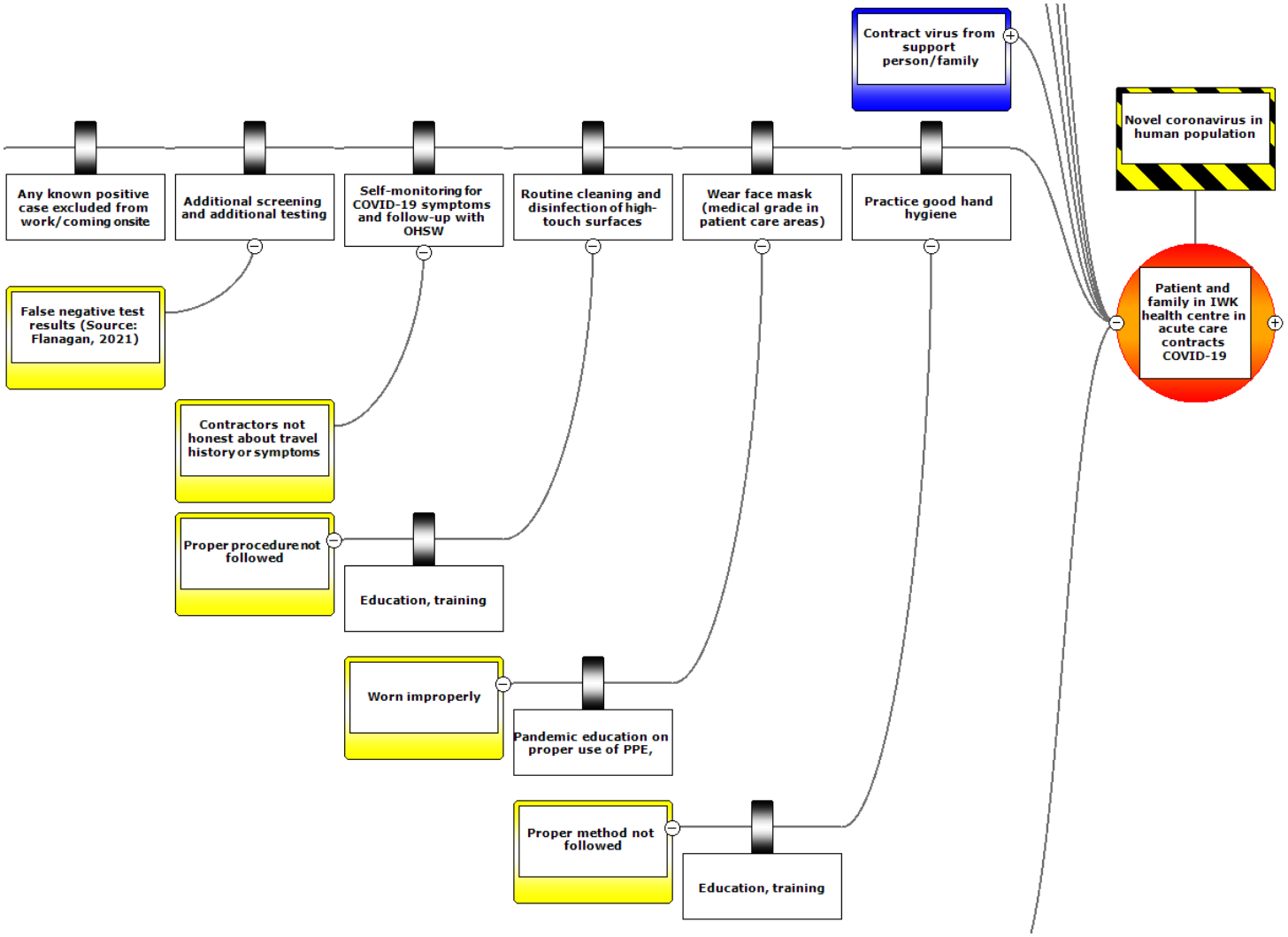

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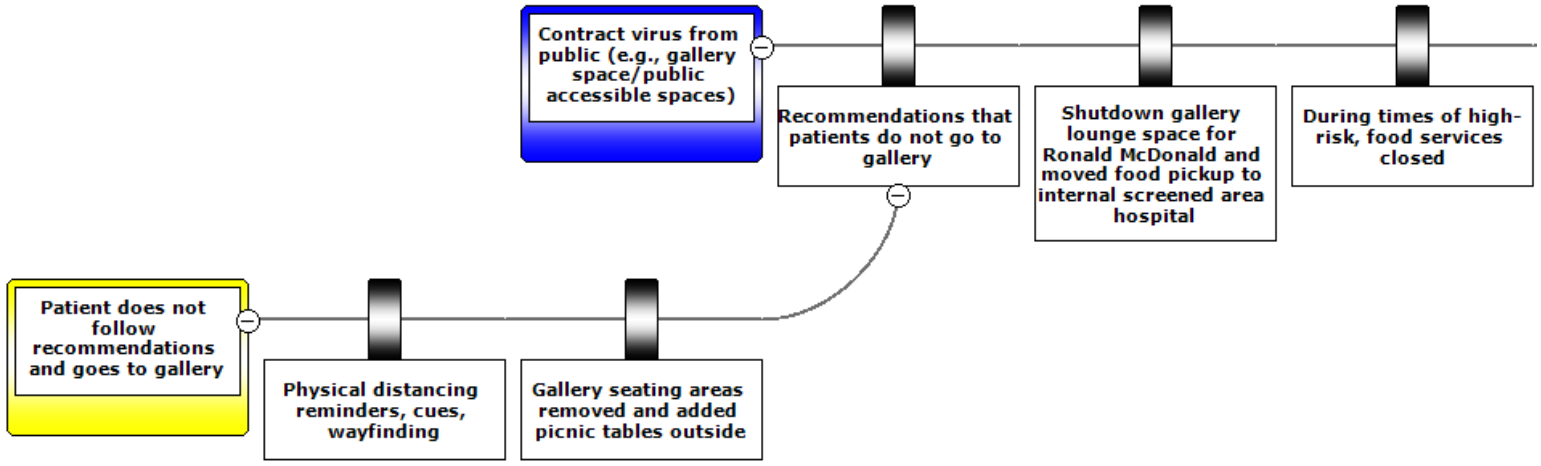

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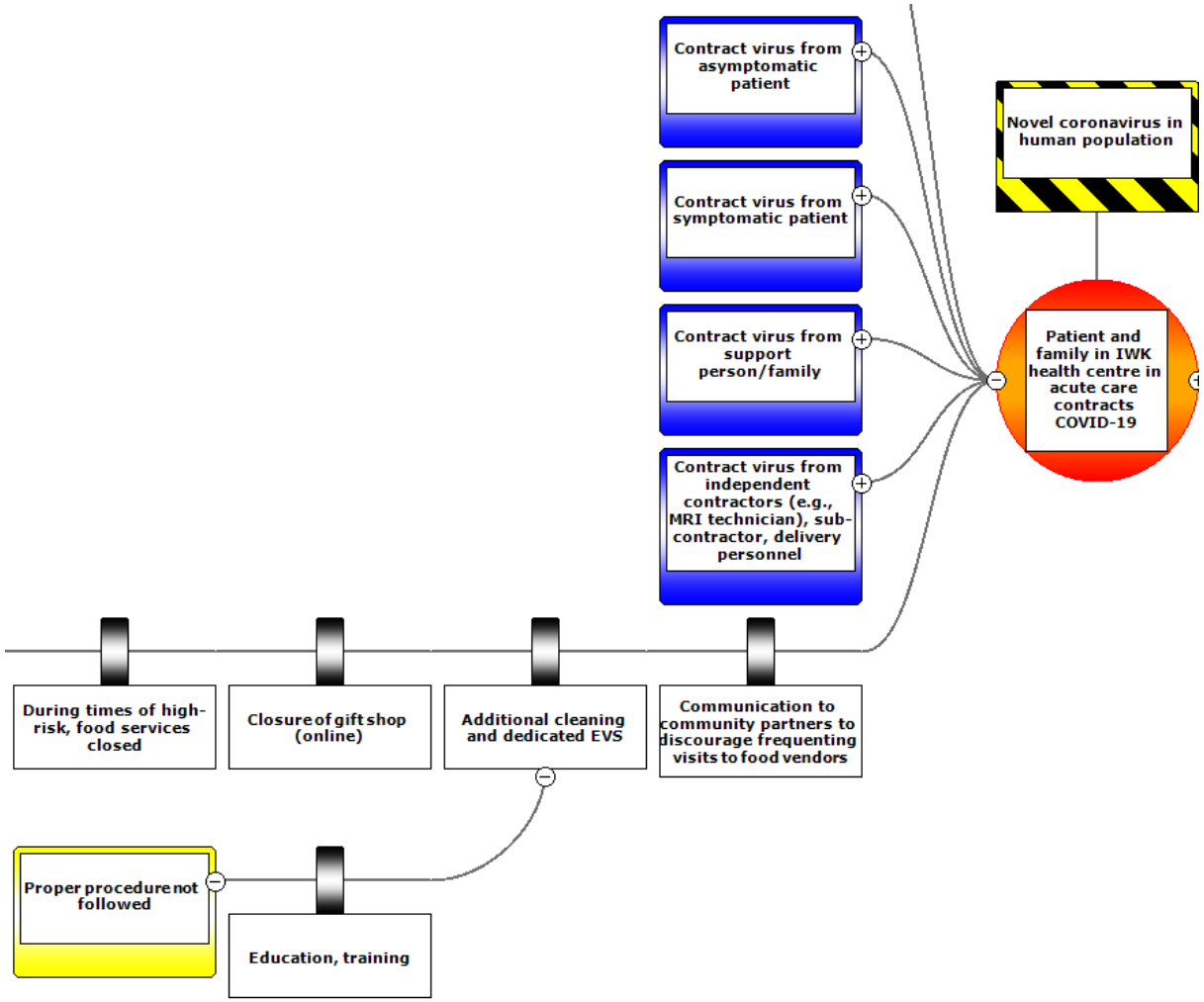

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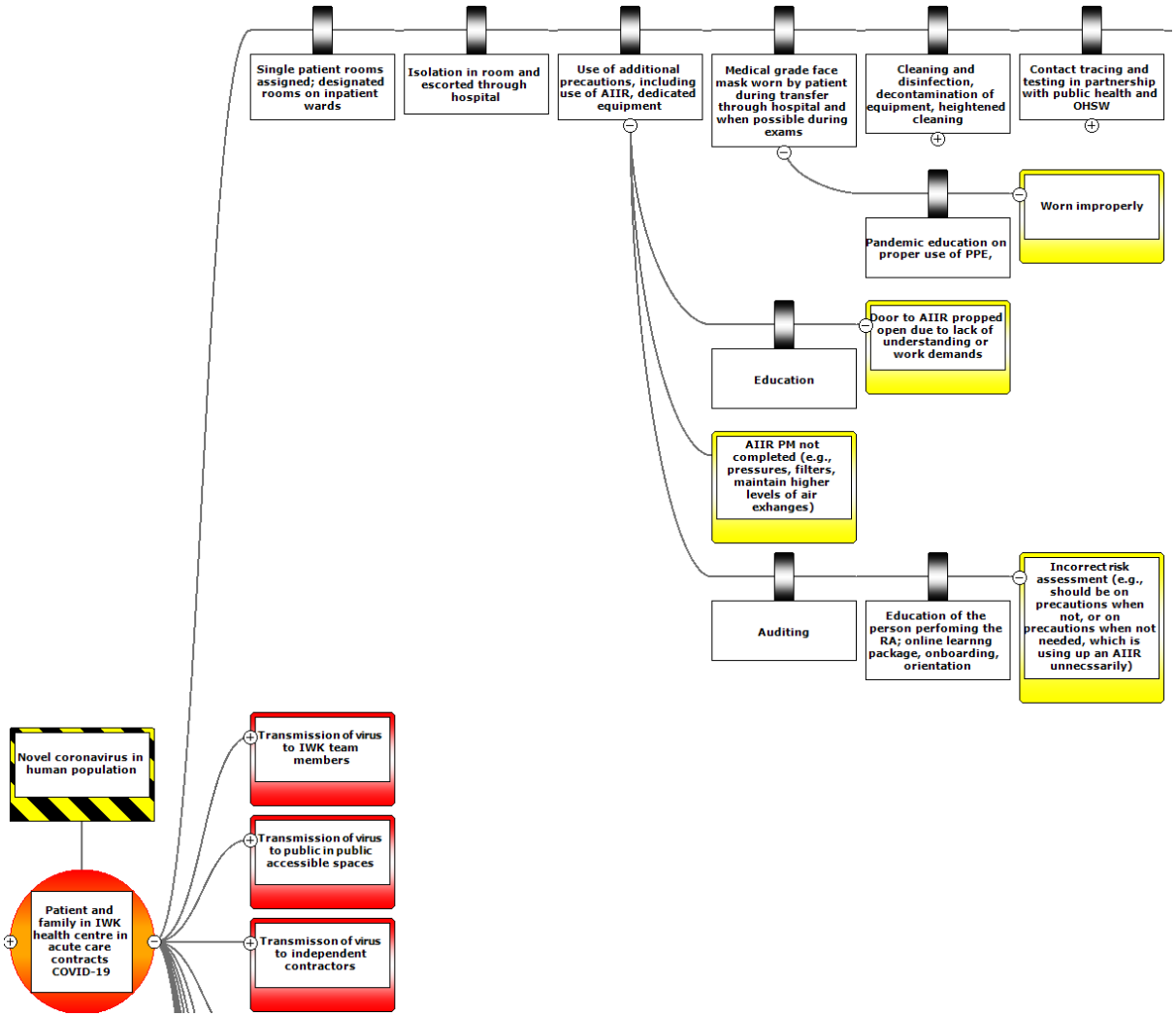

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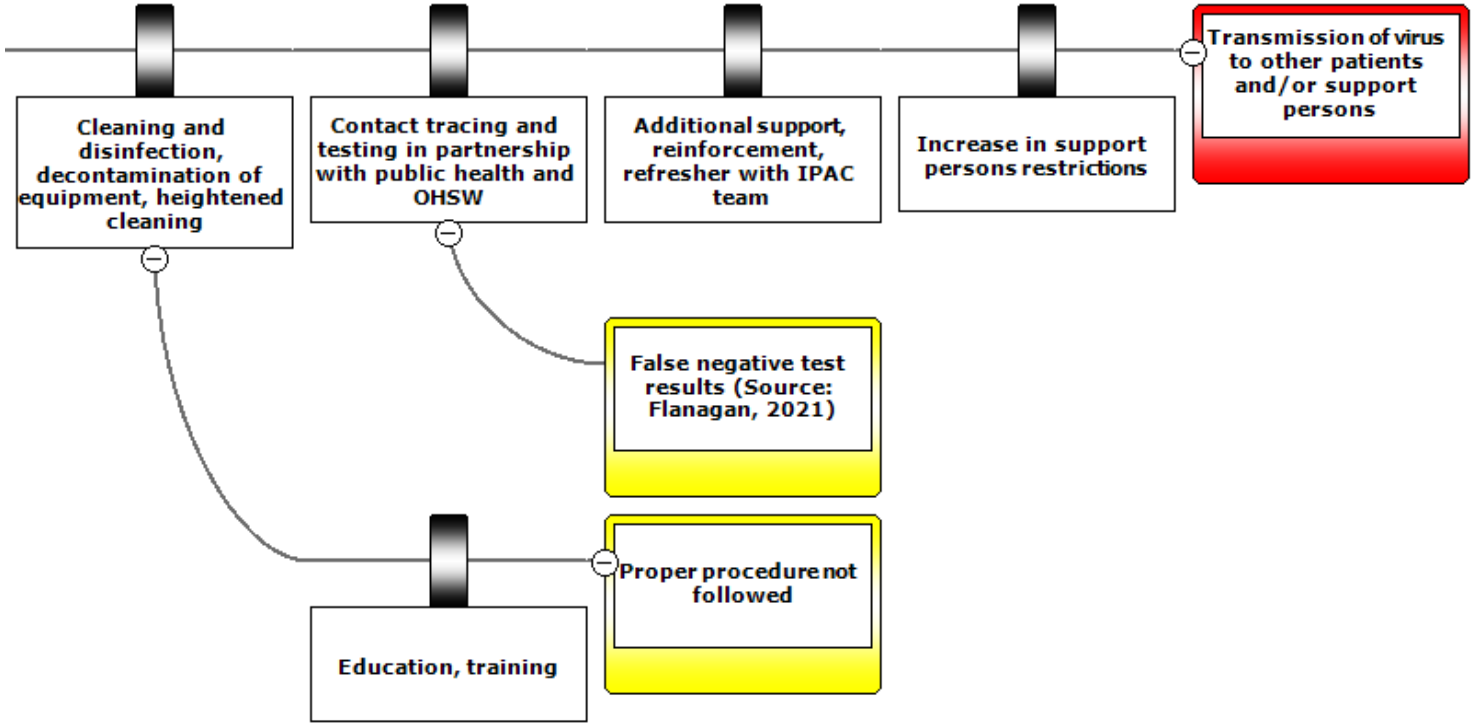

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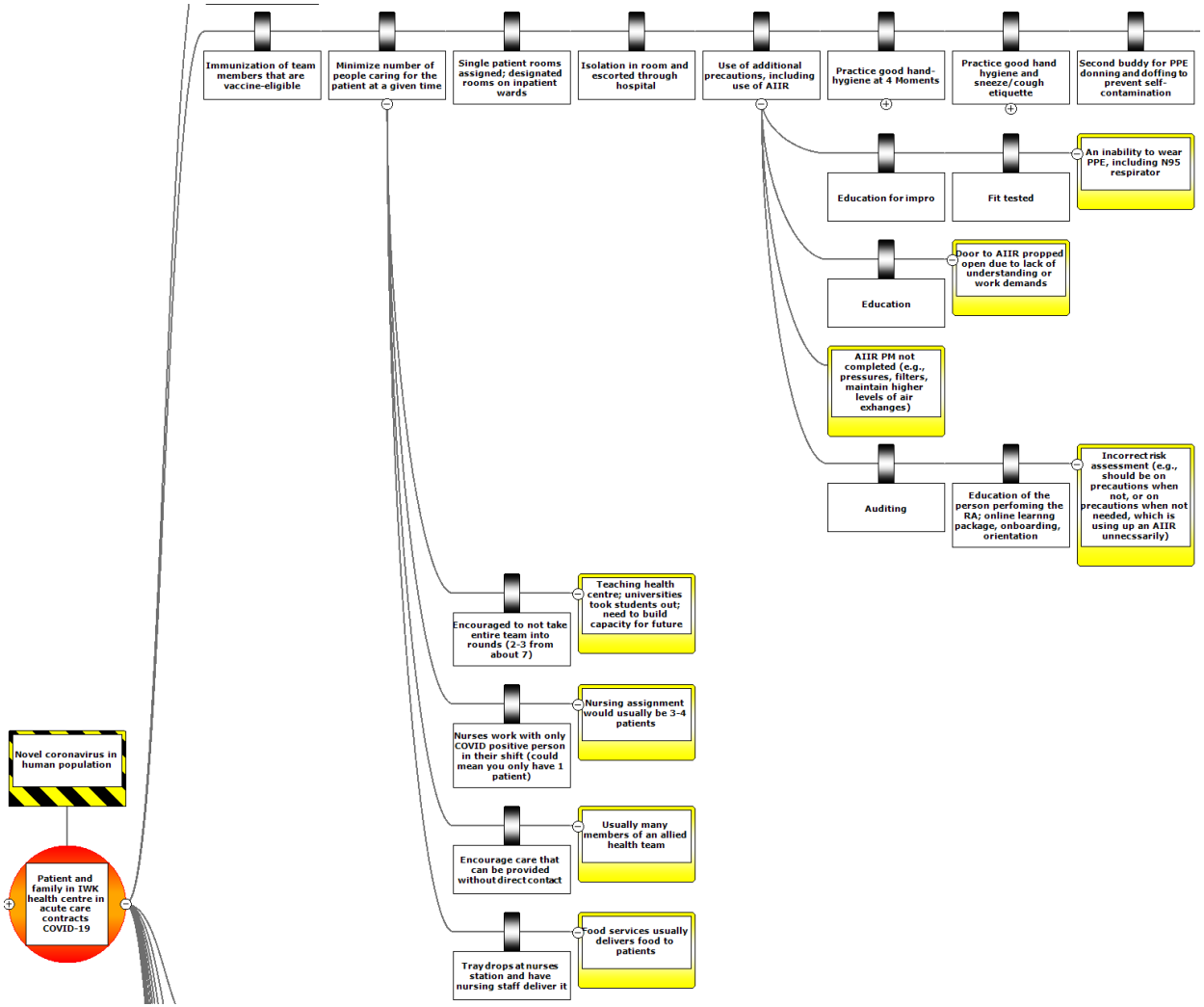

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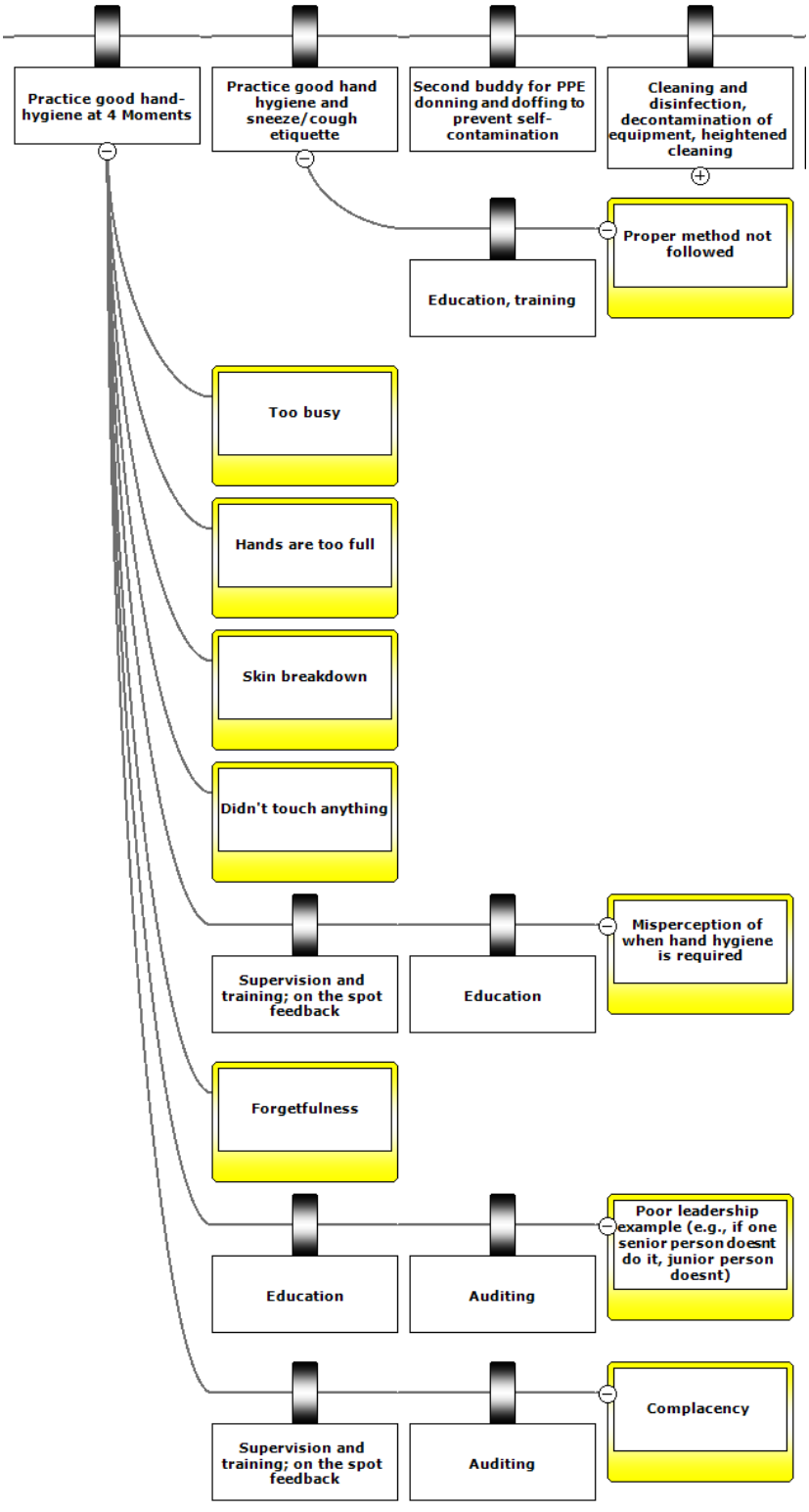

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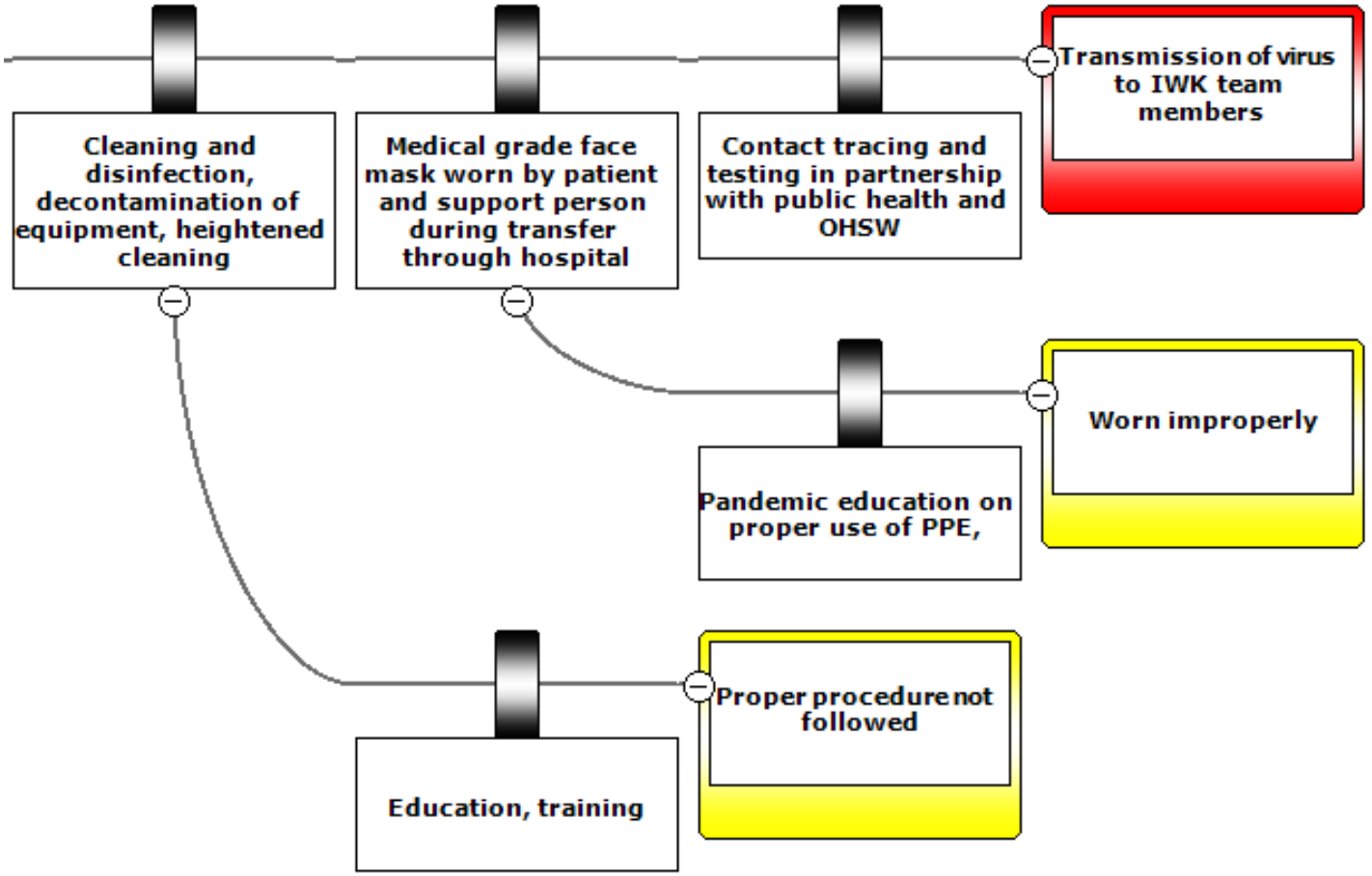

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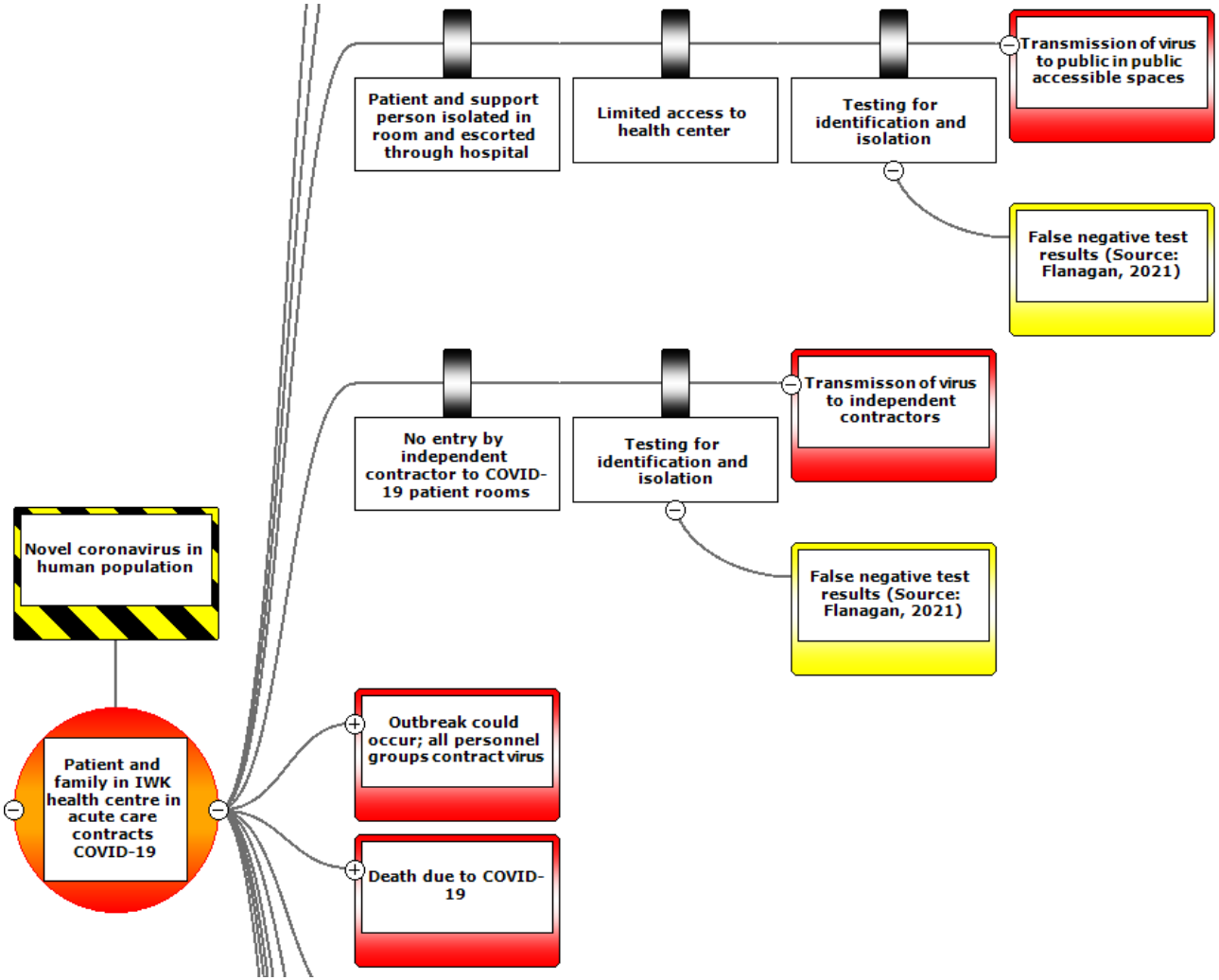

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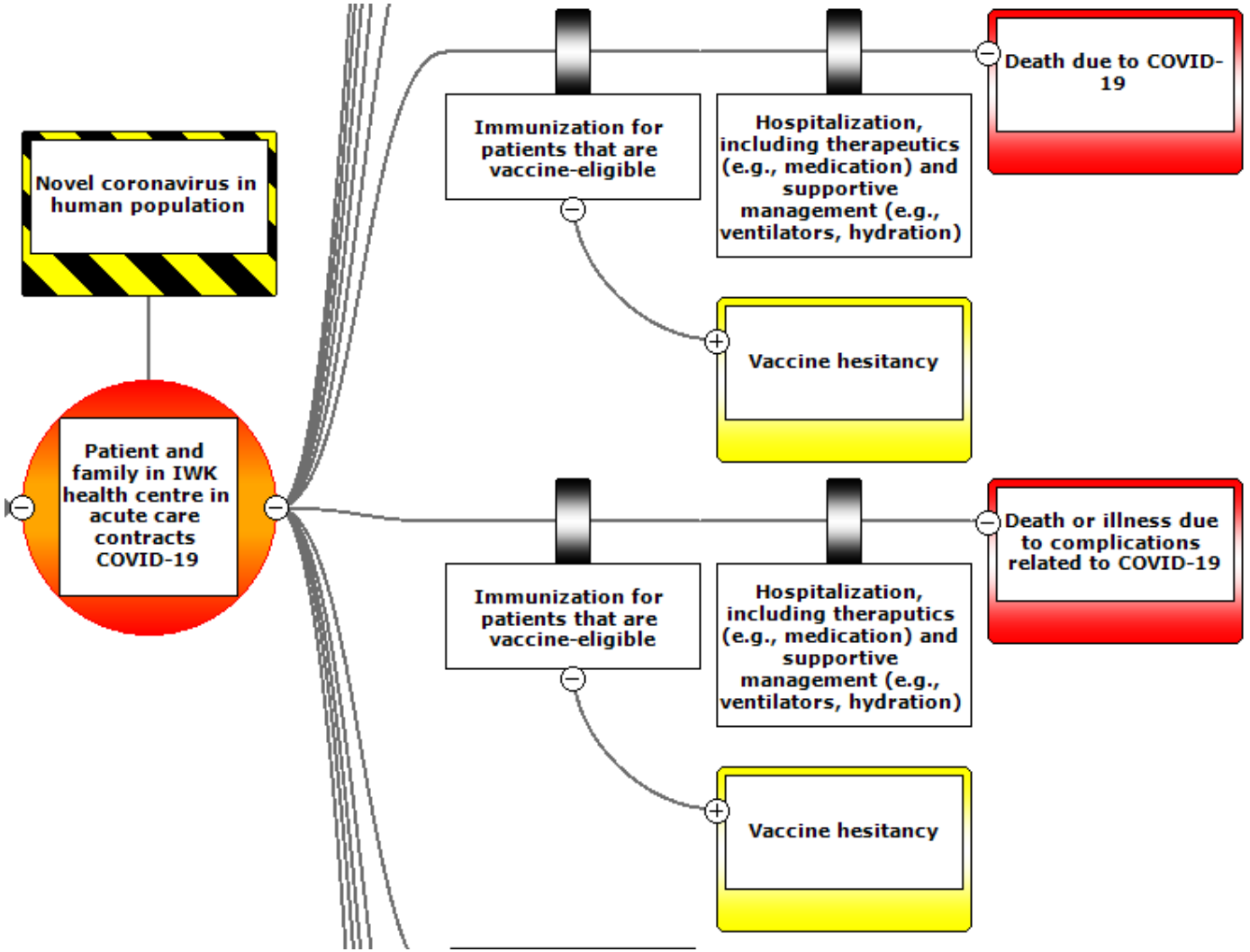

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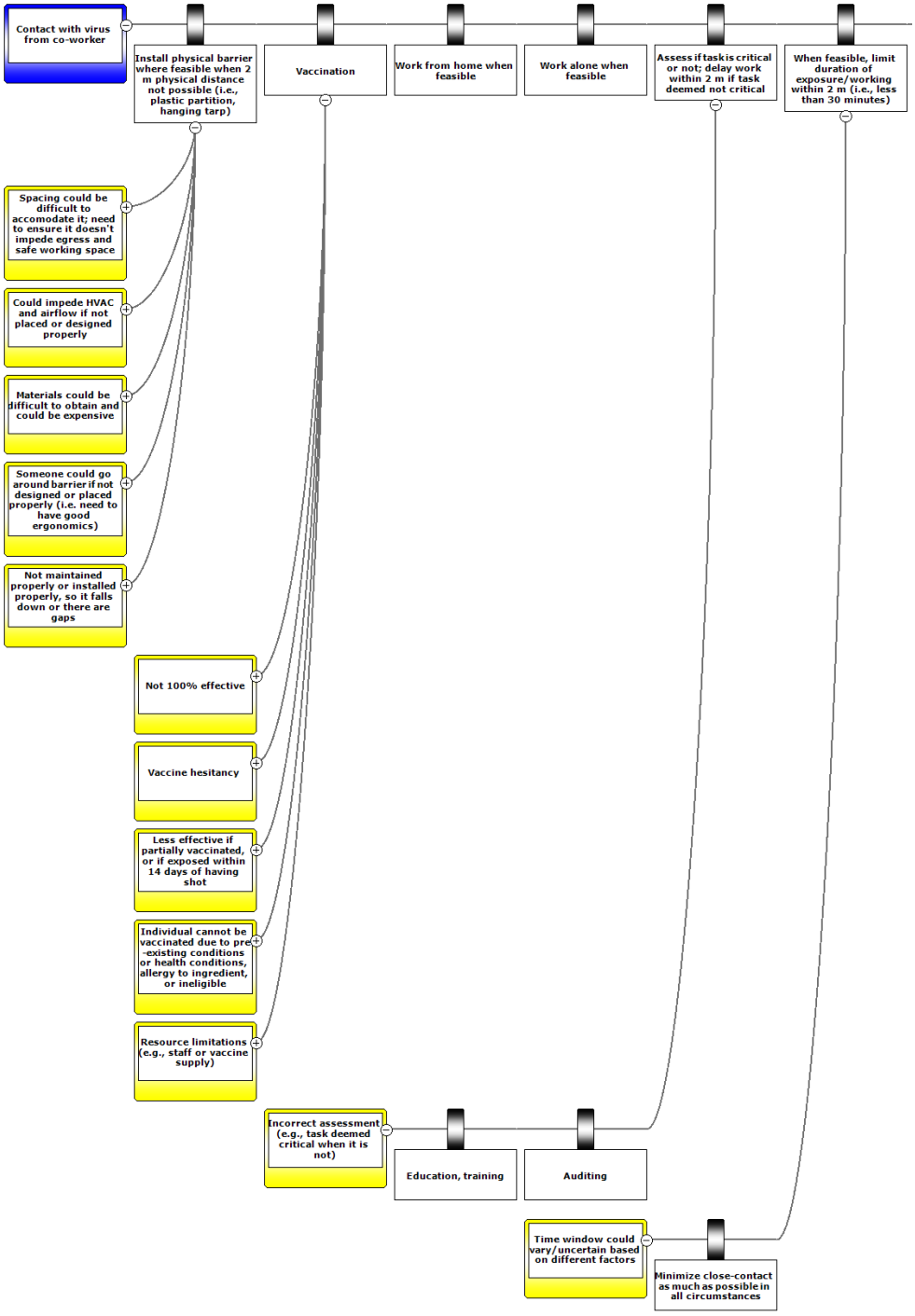
Appendix B BCFSC Wood Pellet Facility Bow Tie Diagram



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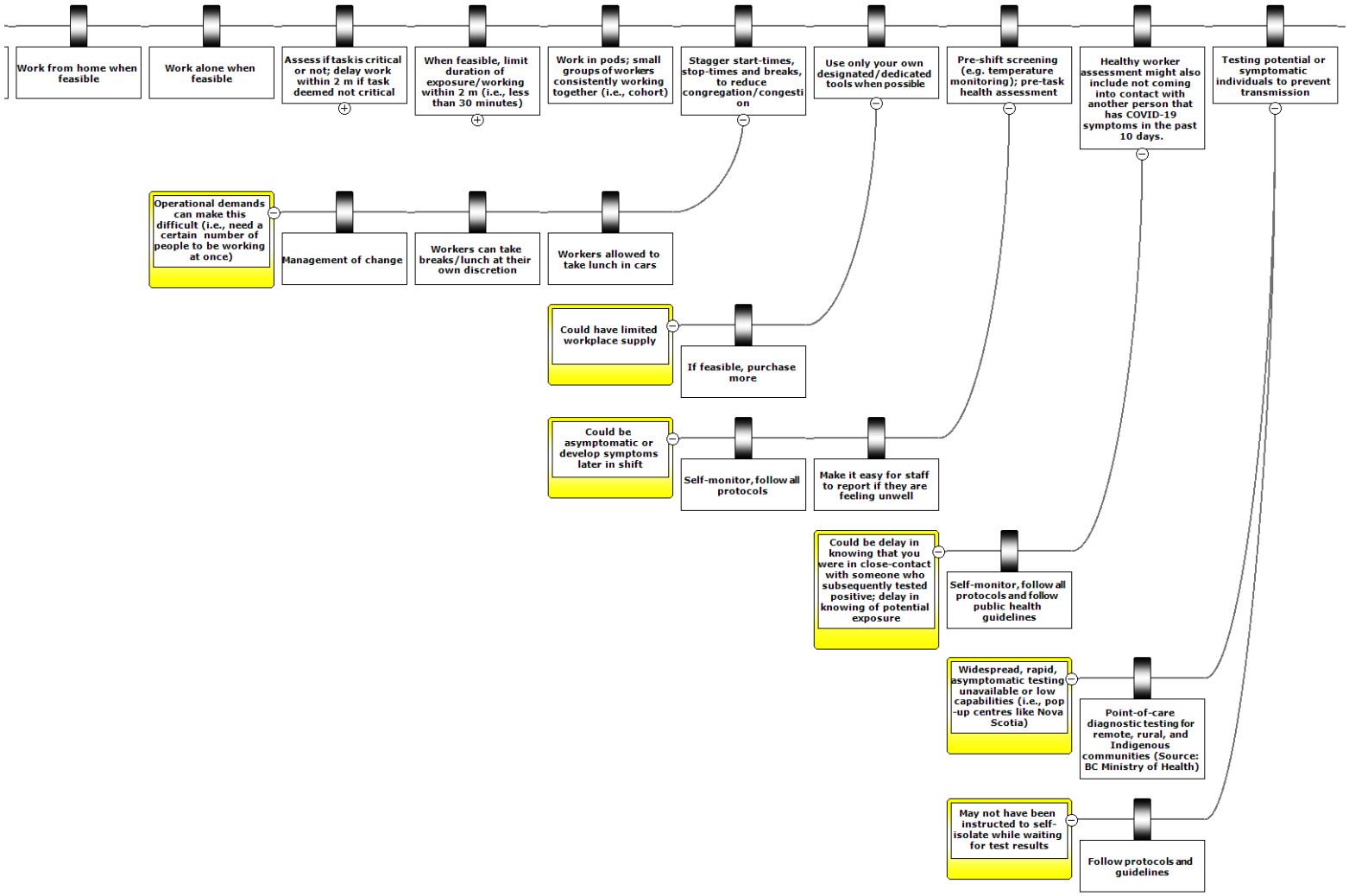

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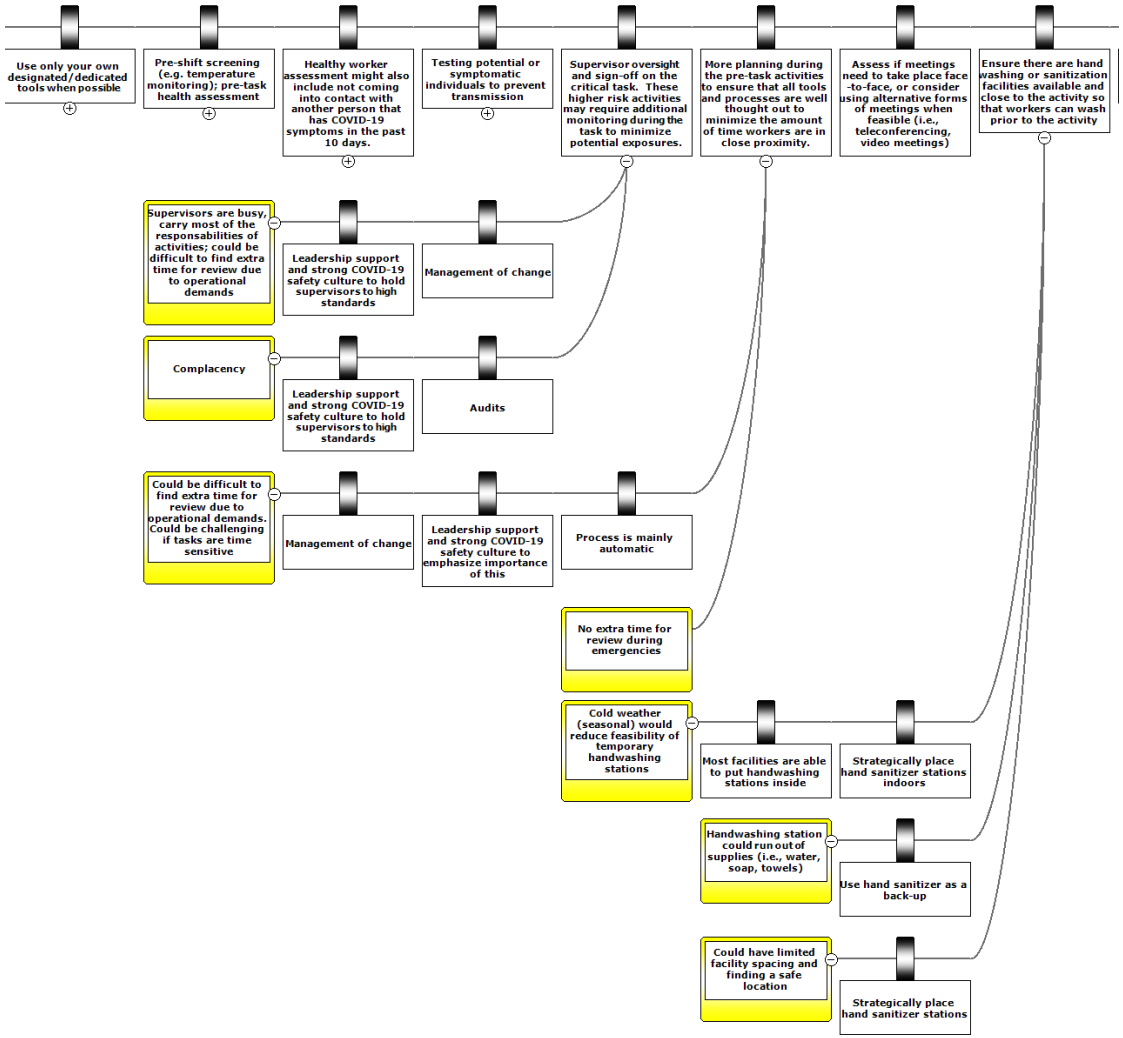

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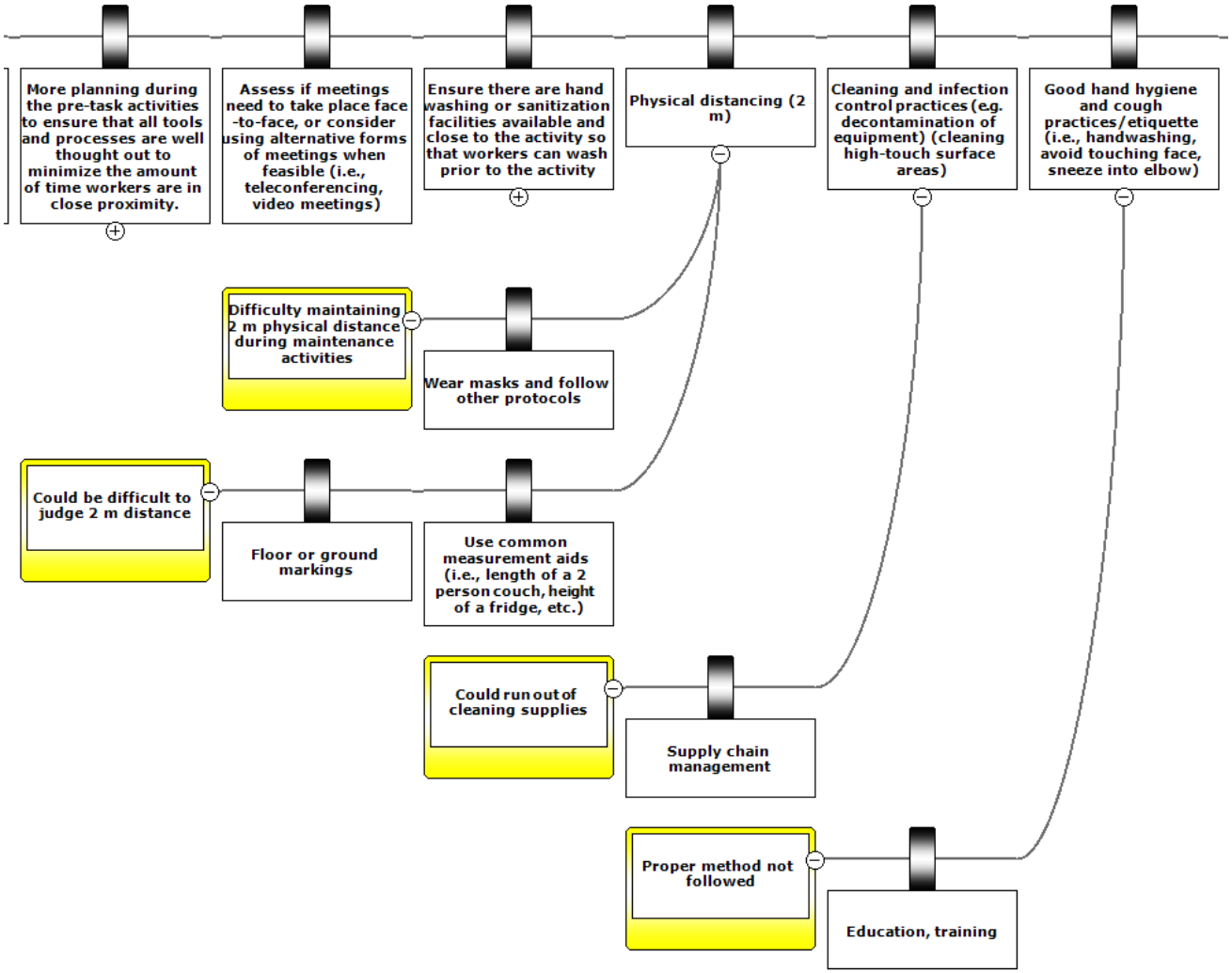

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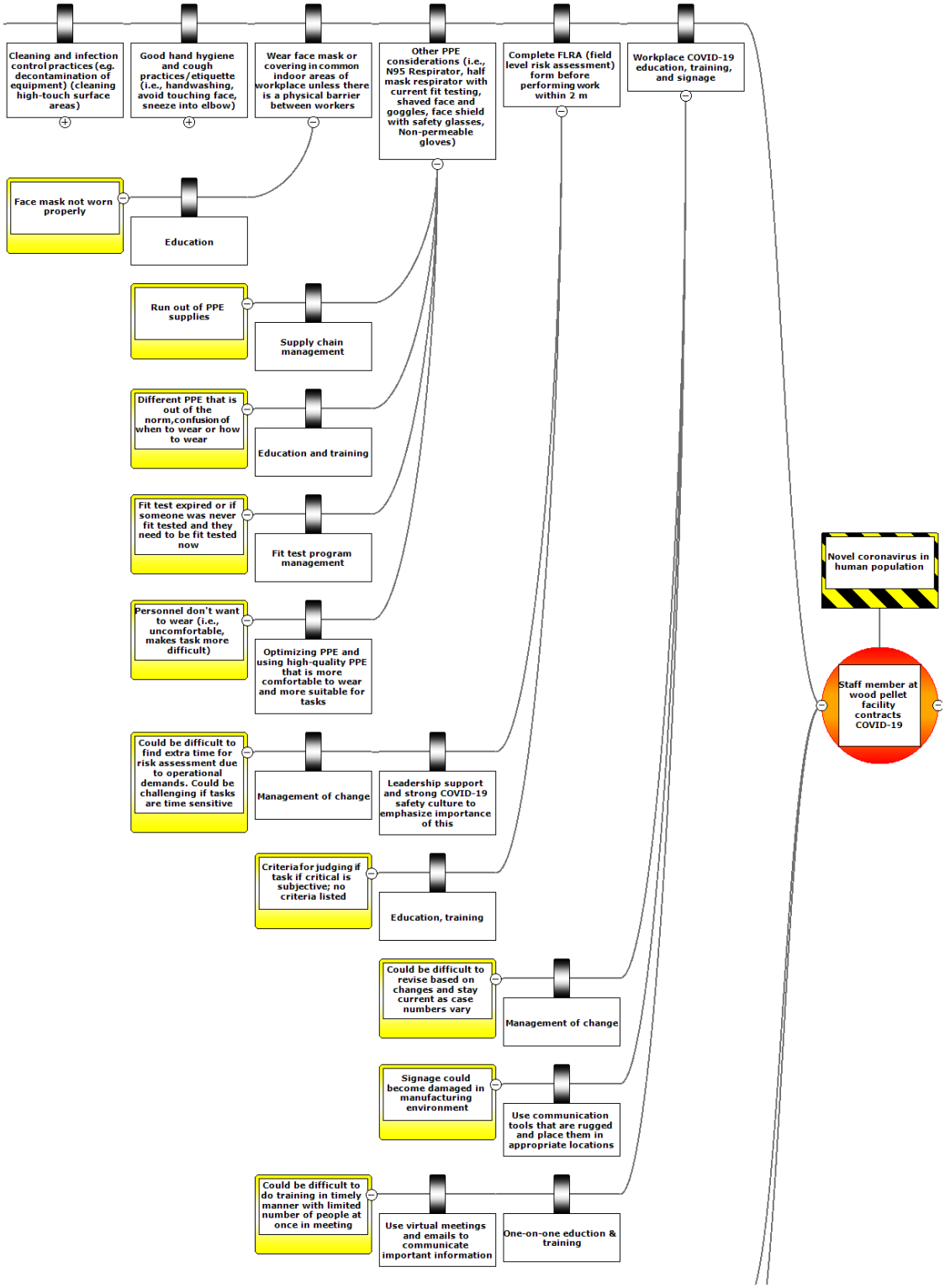

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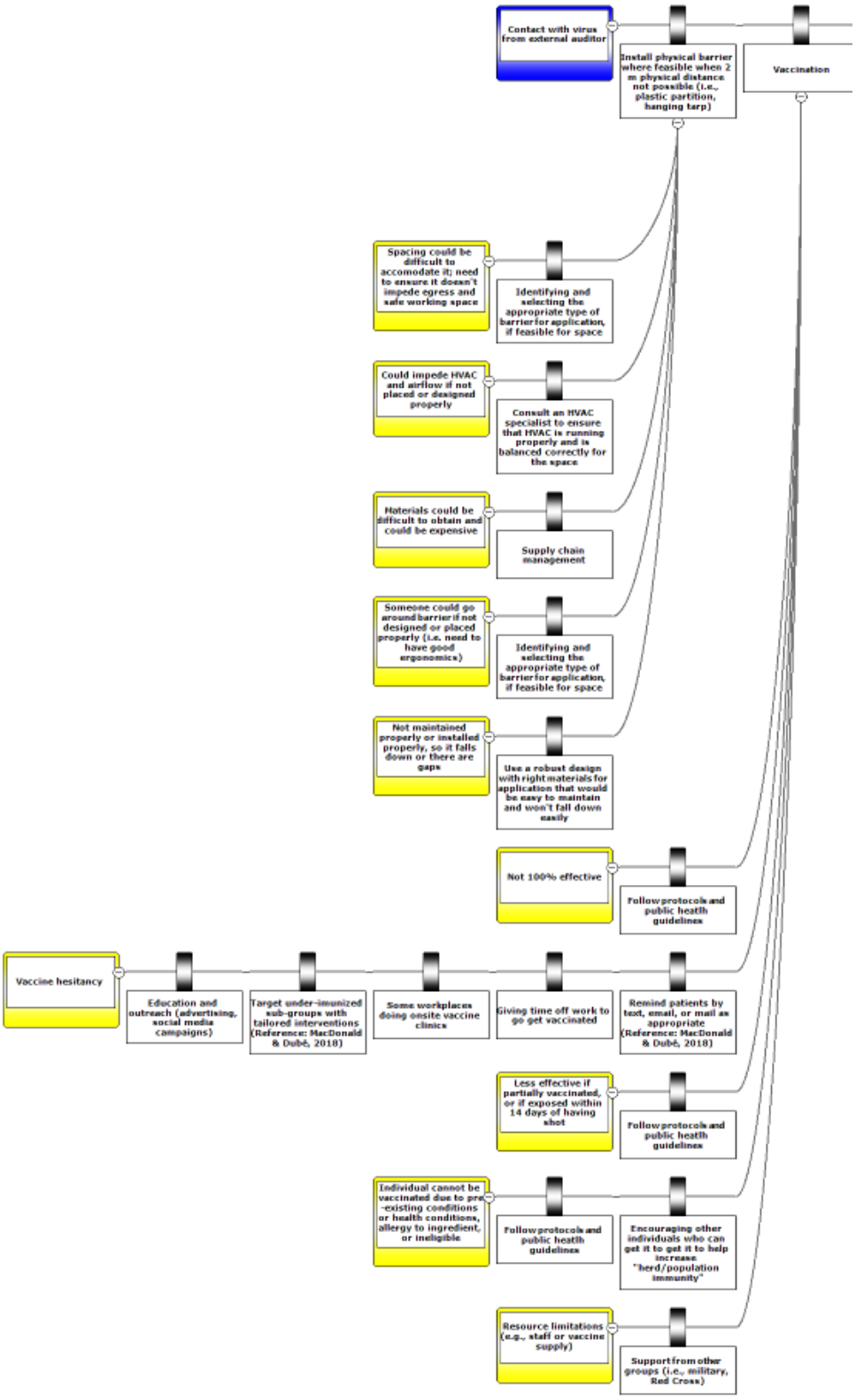

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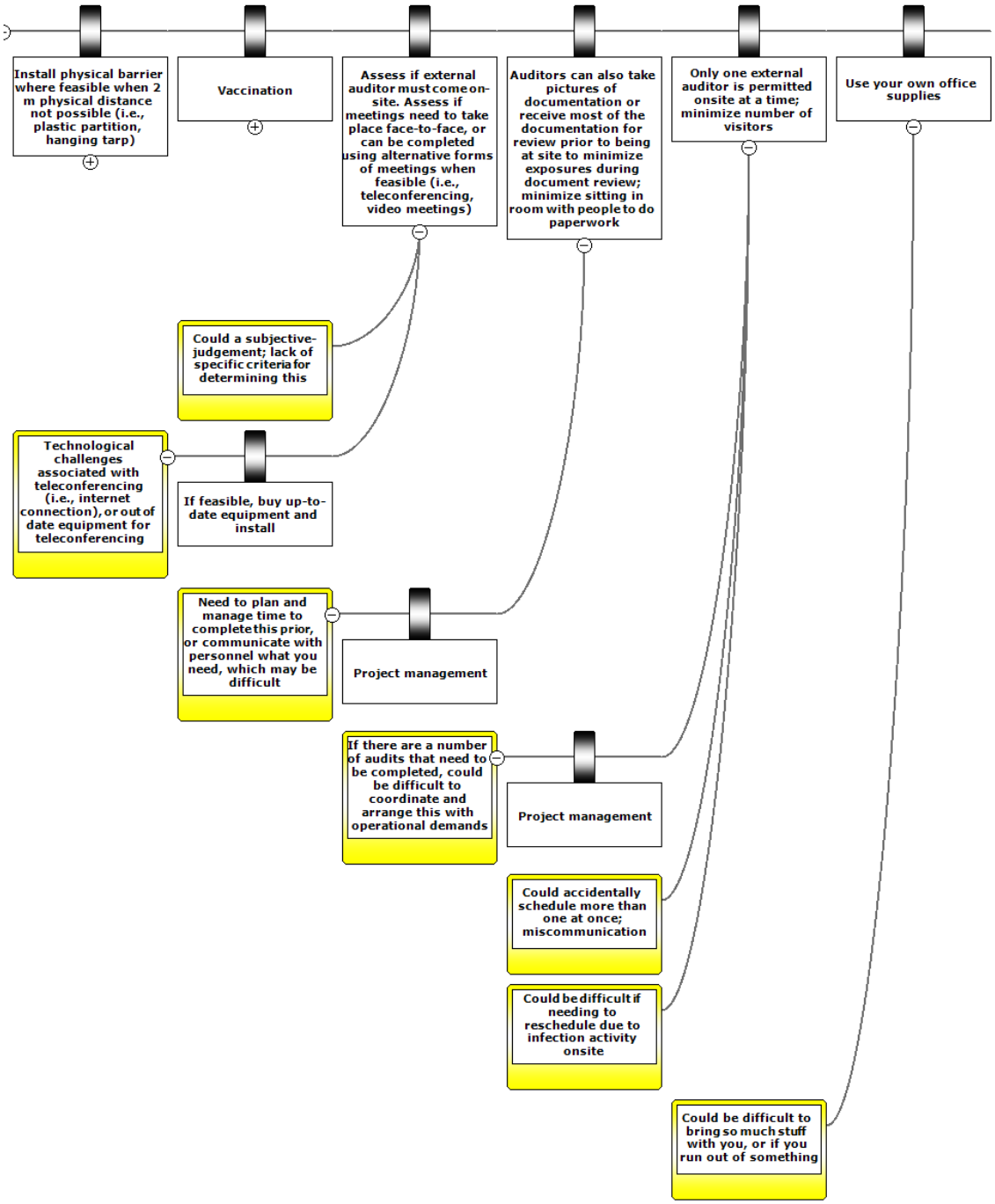

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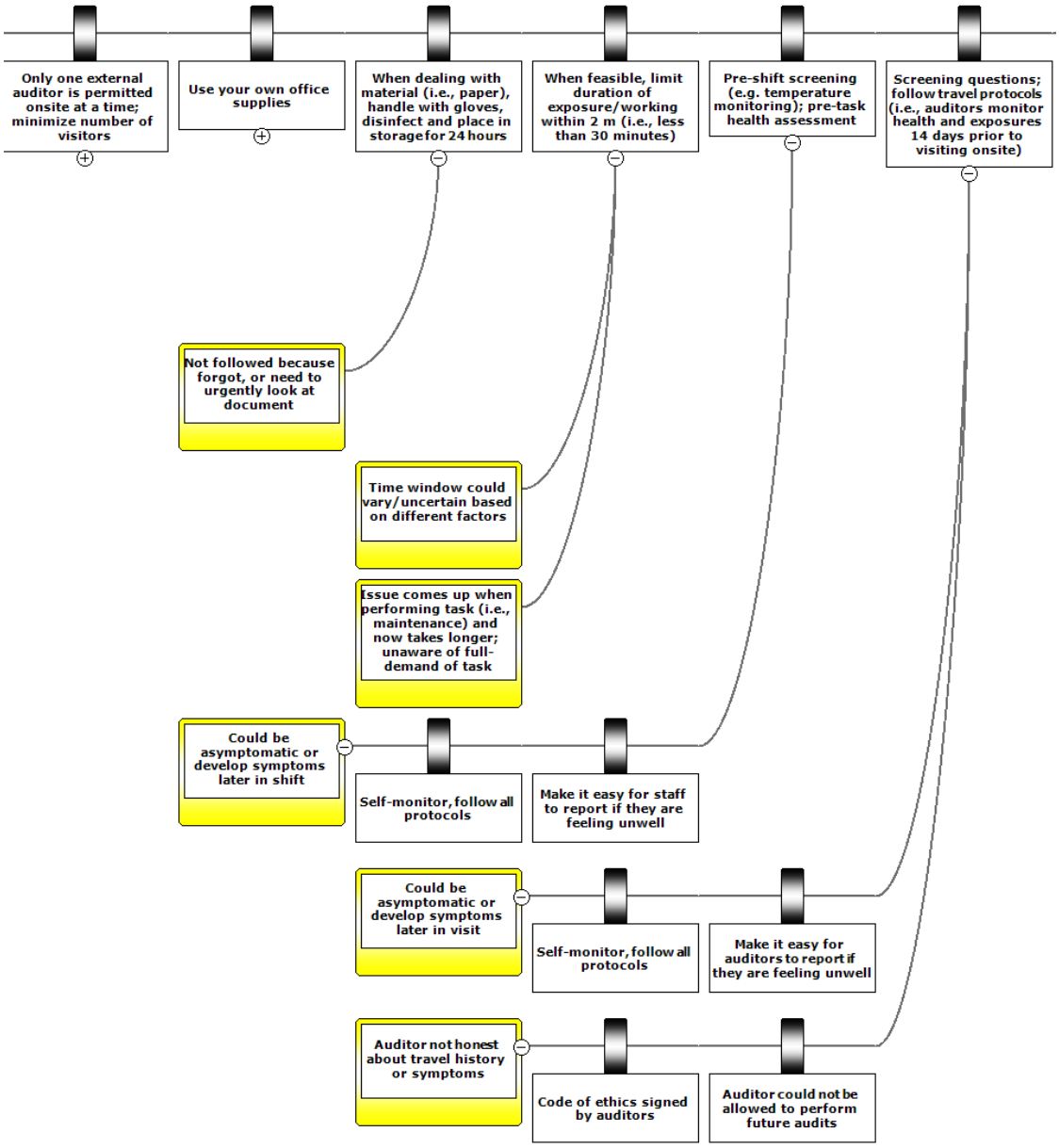

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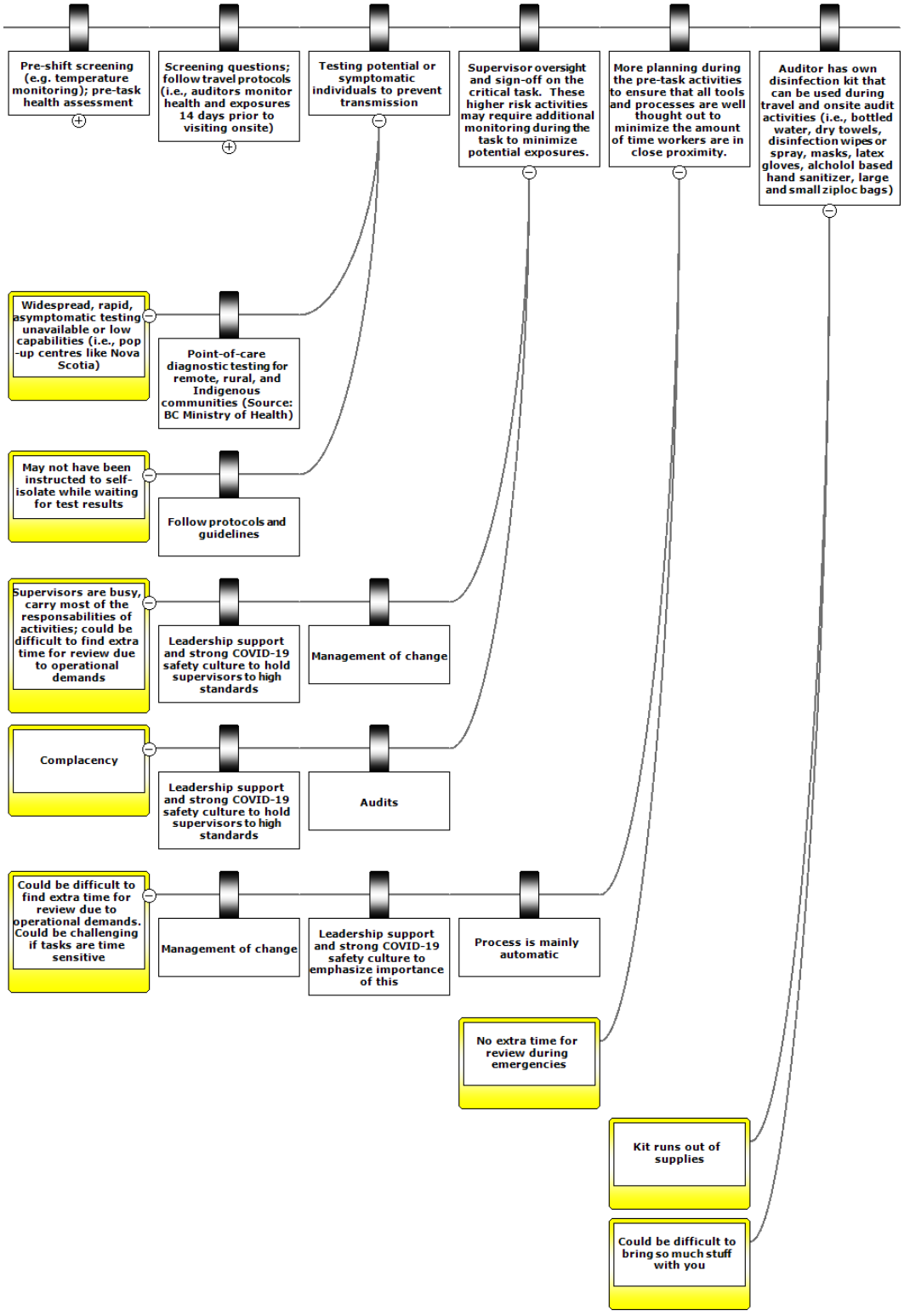
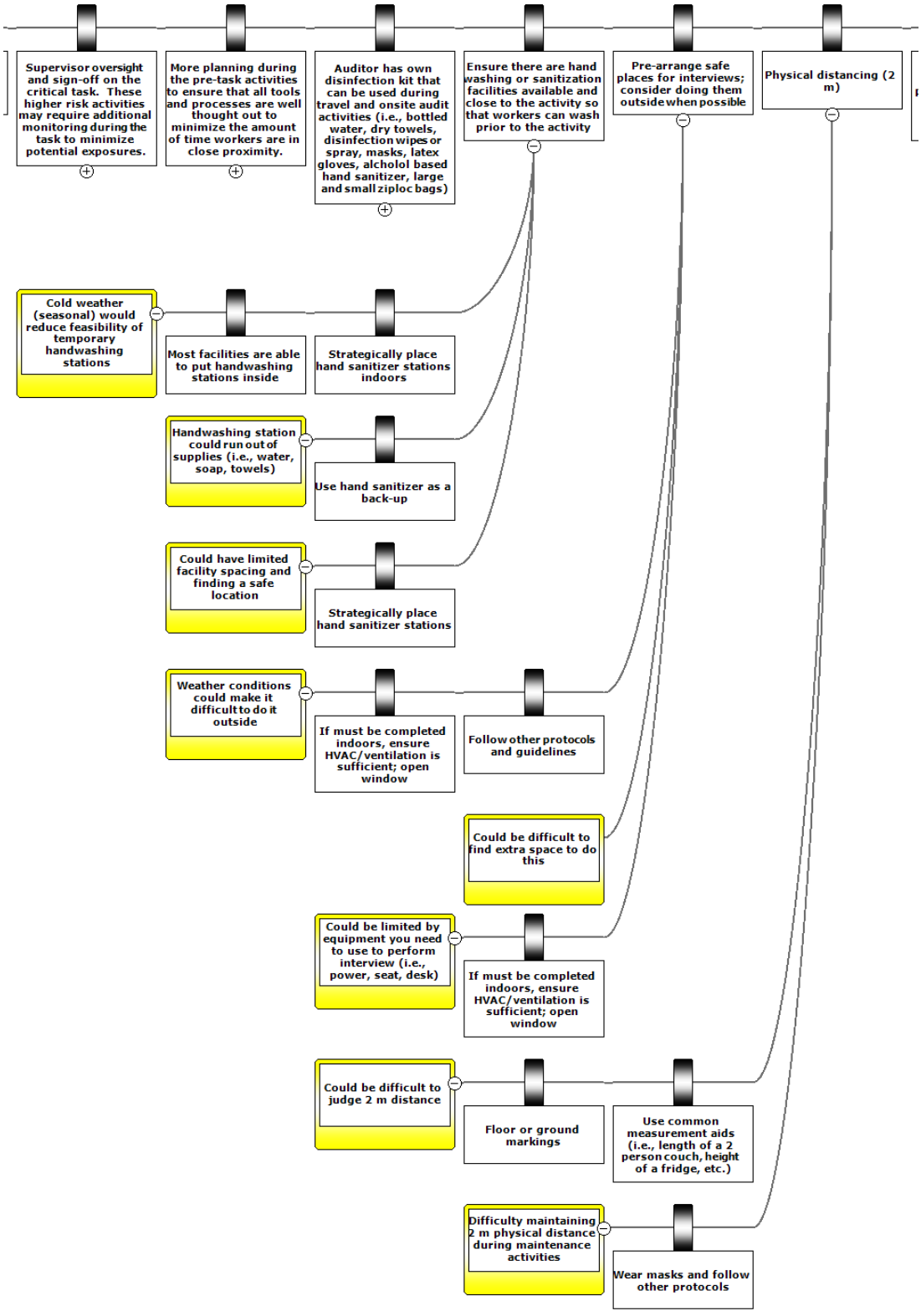


Figure B-9. BCFSC wood pellet facility COVID-19 bow tie diagram part 9



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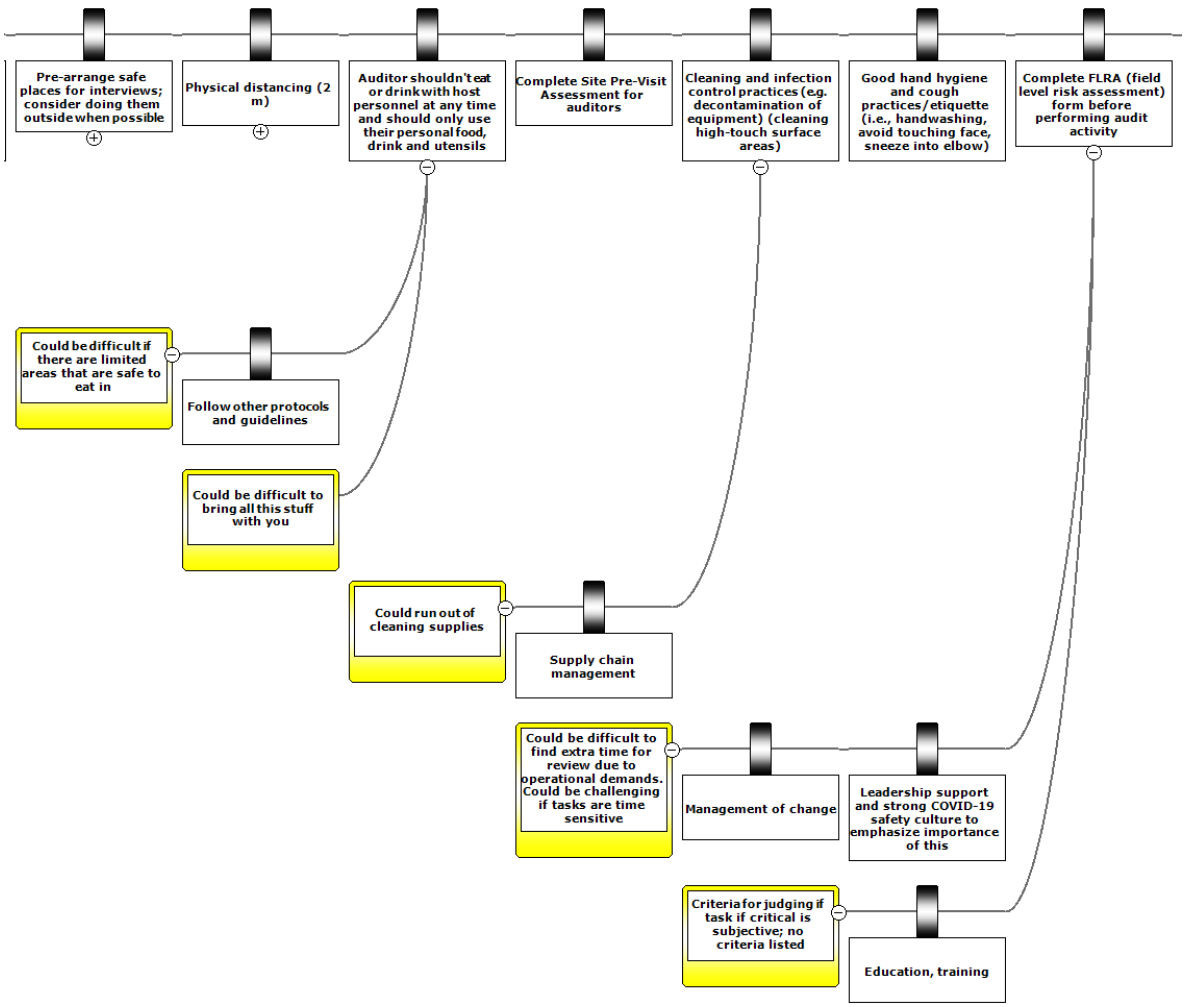

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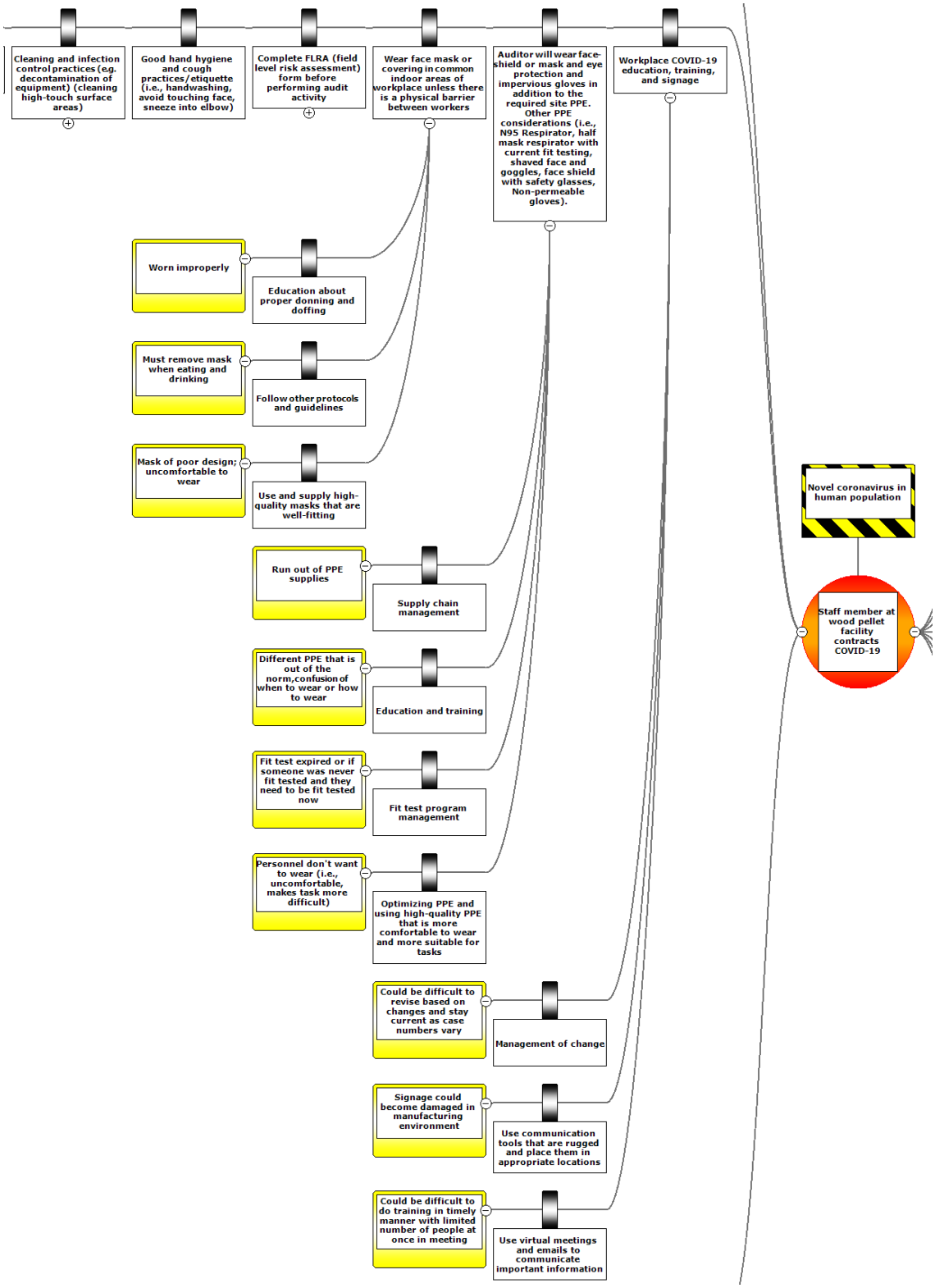

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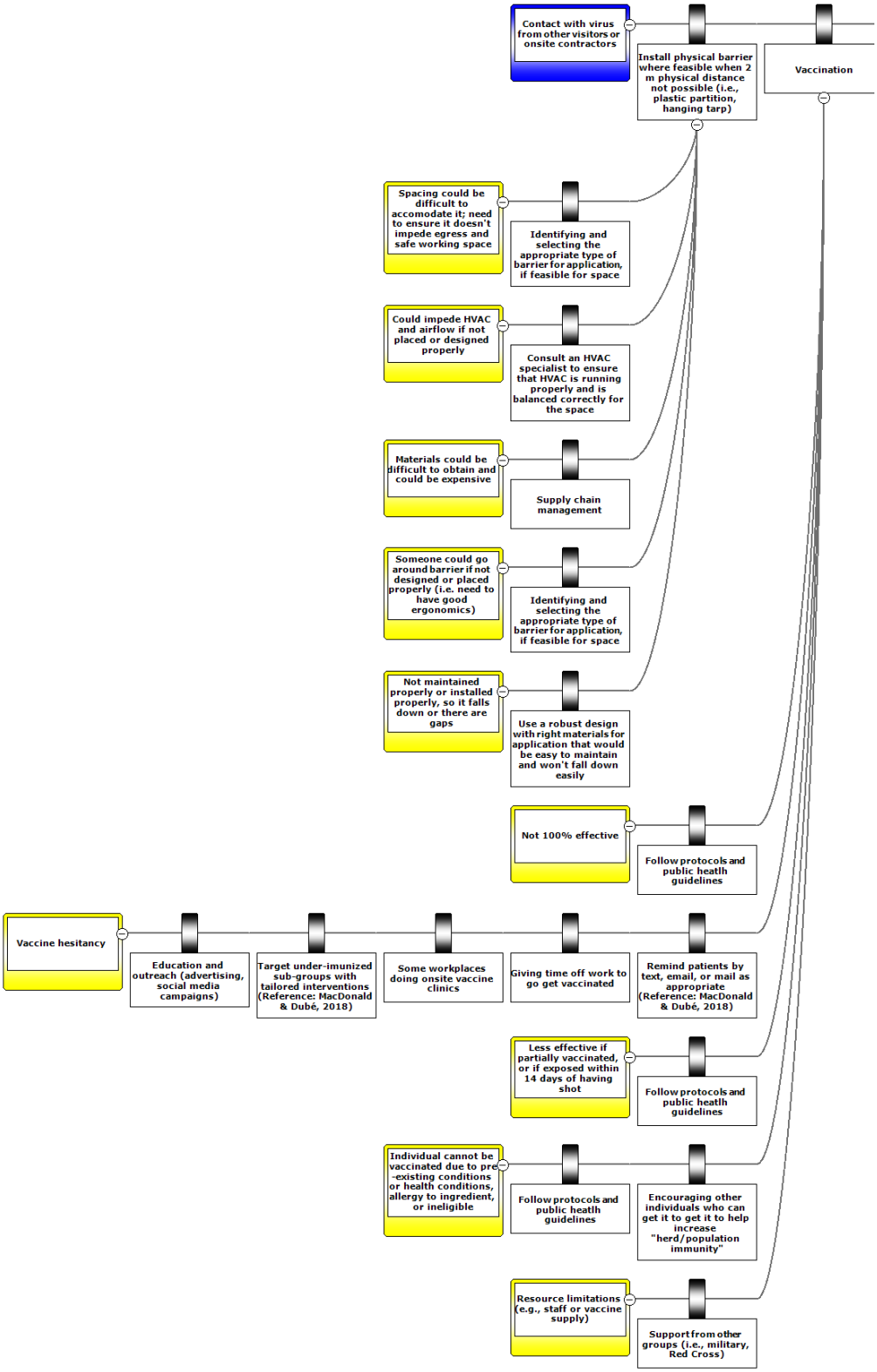

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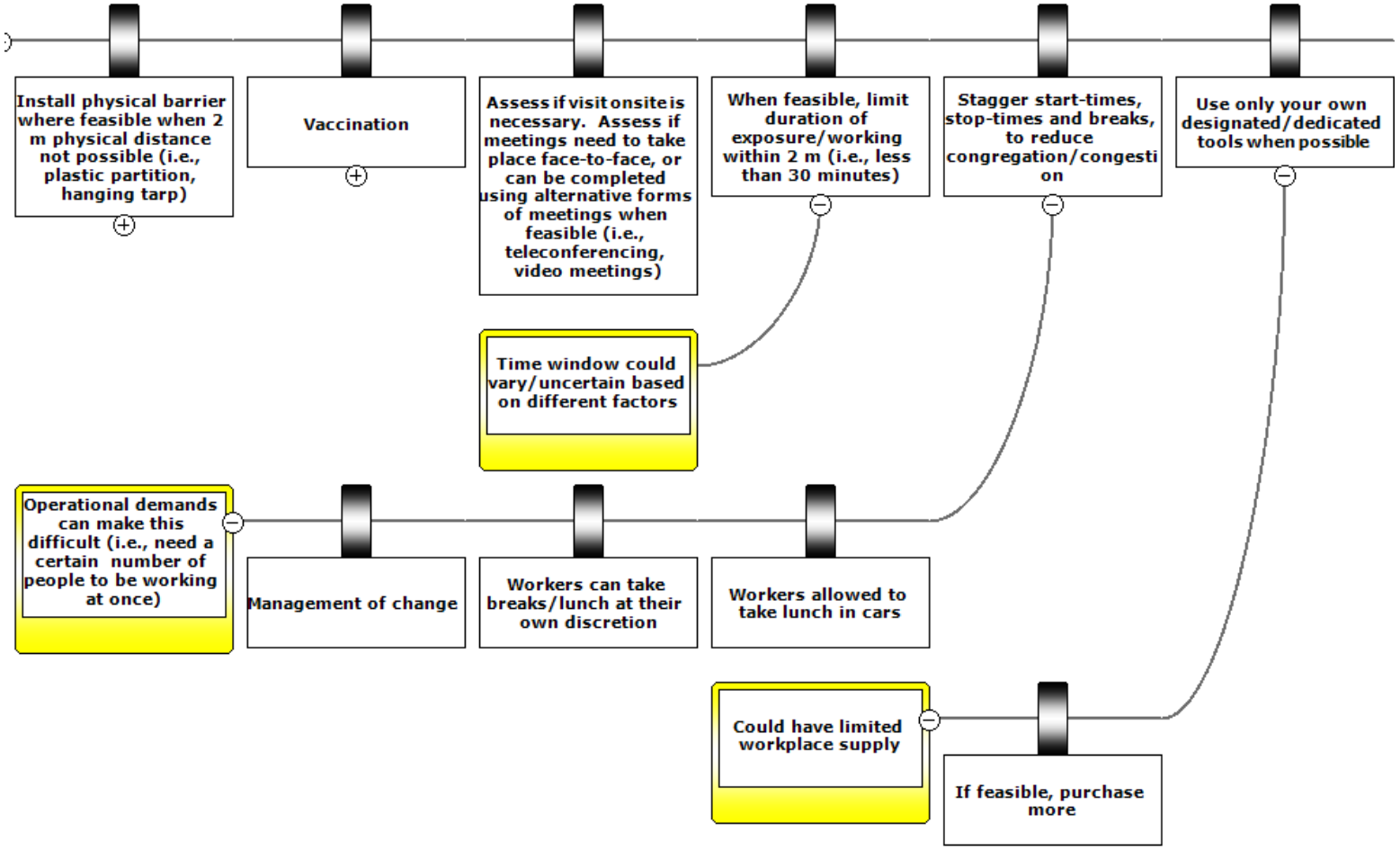


Figure B-14. BCFSC wood pellet facility COVID-19 bow tie diagram part 14

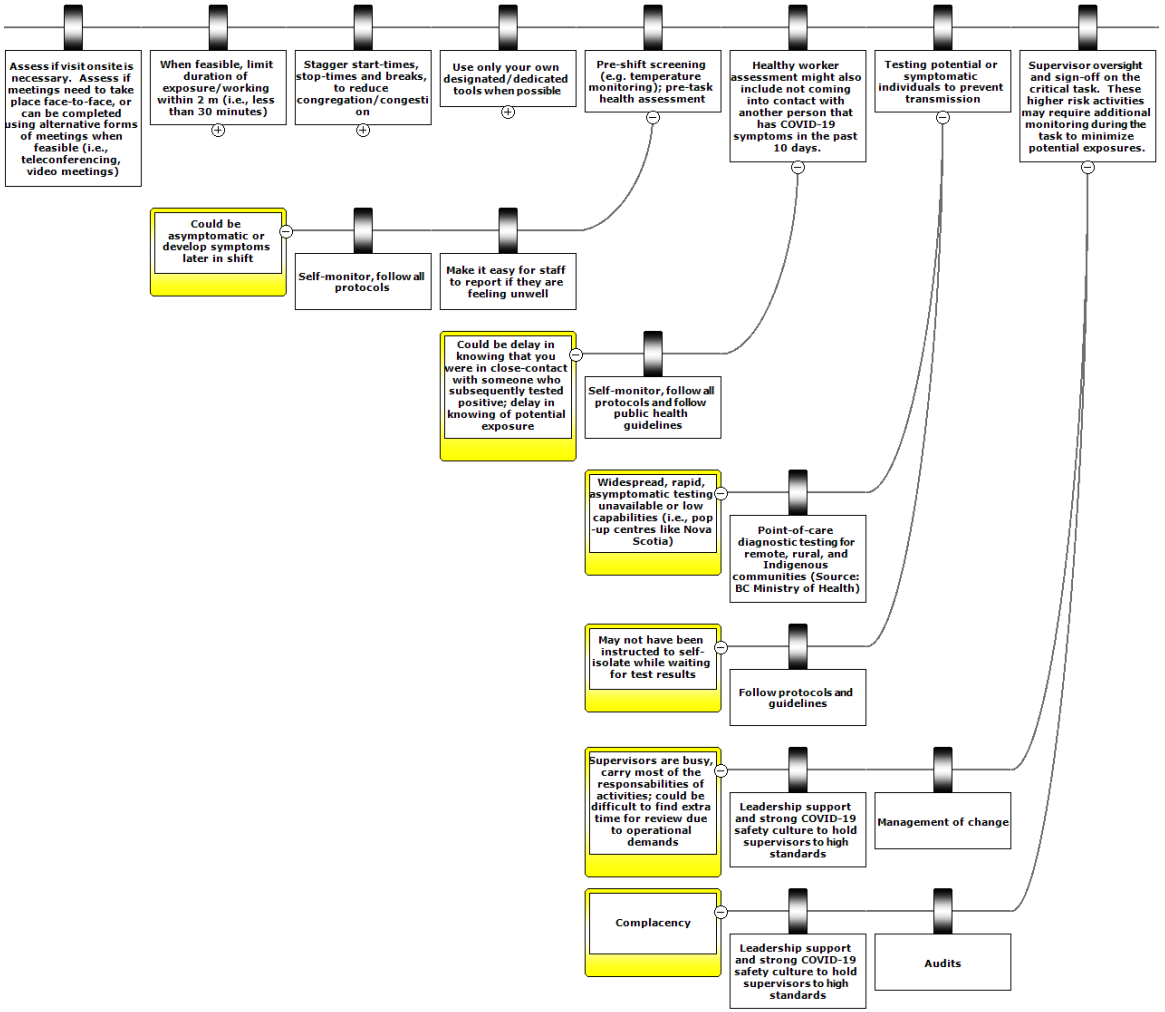
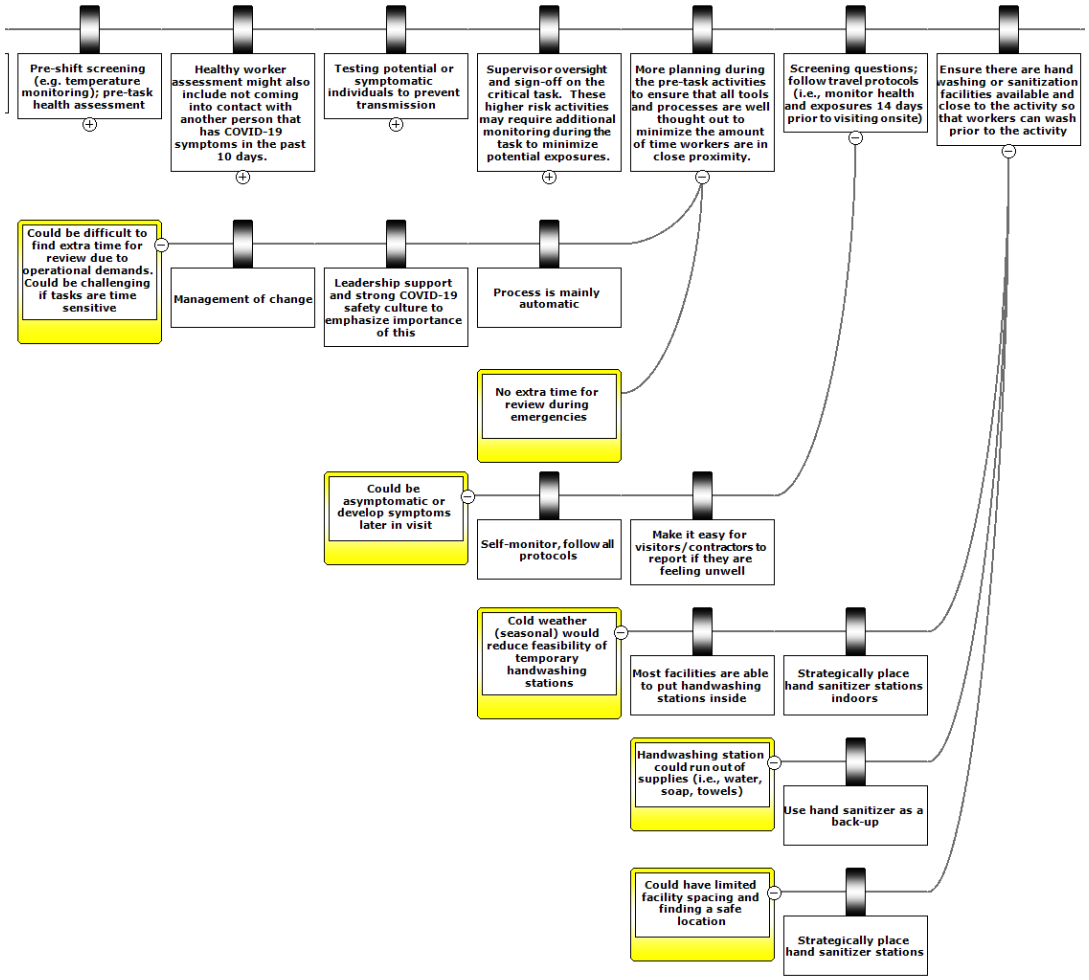


Figure B-15. BCFSC wood pellet facility COVID-19 bow tie diagram part 15



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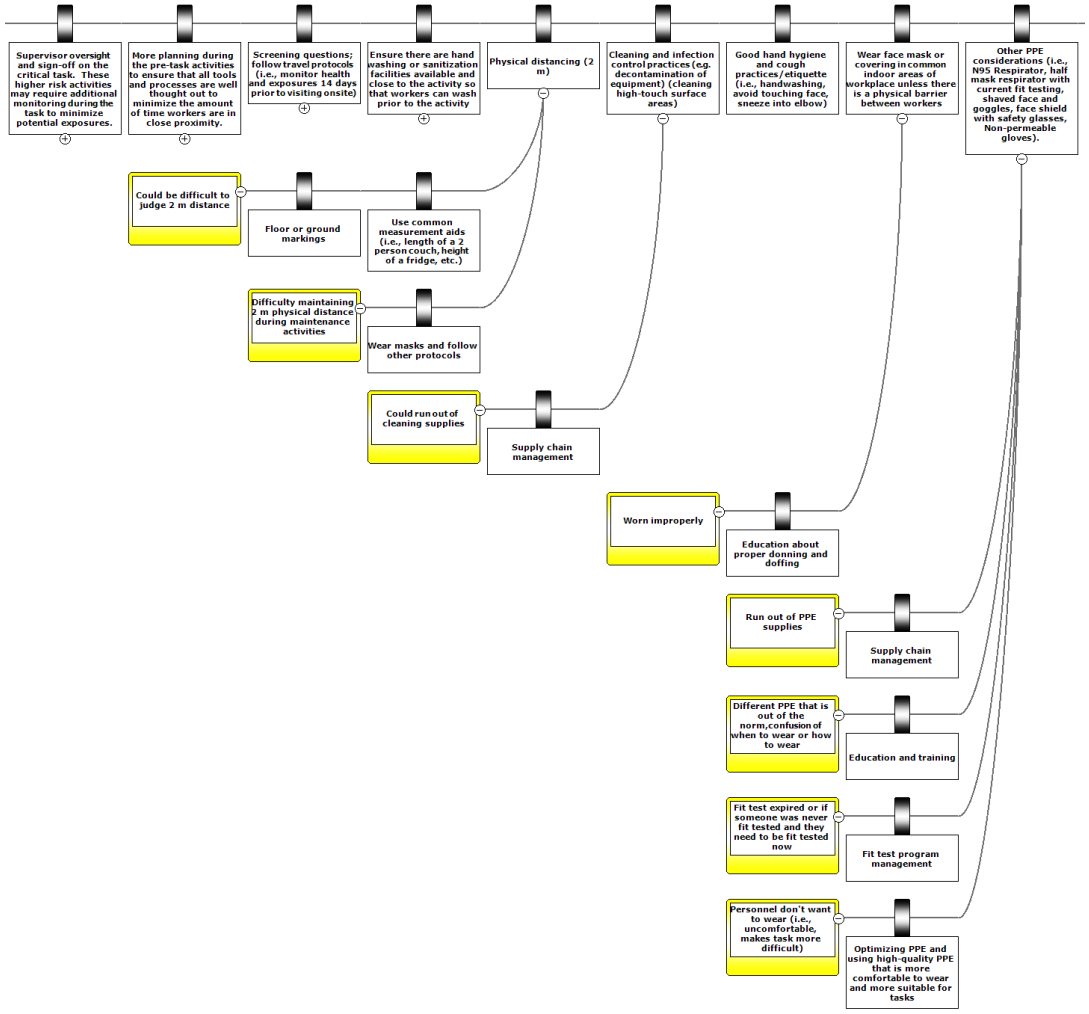

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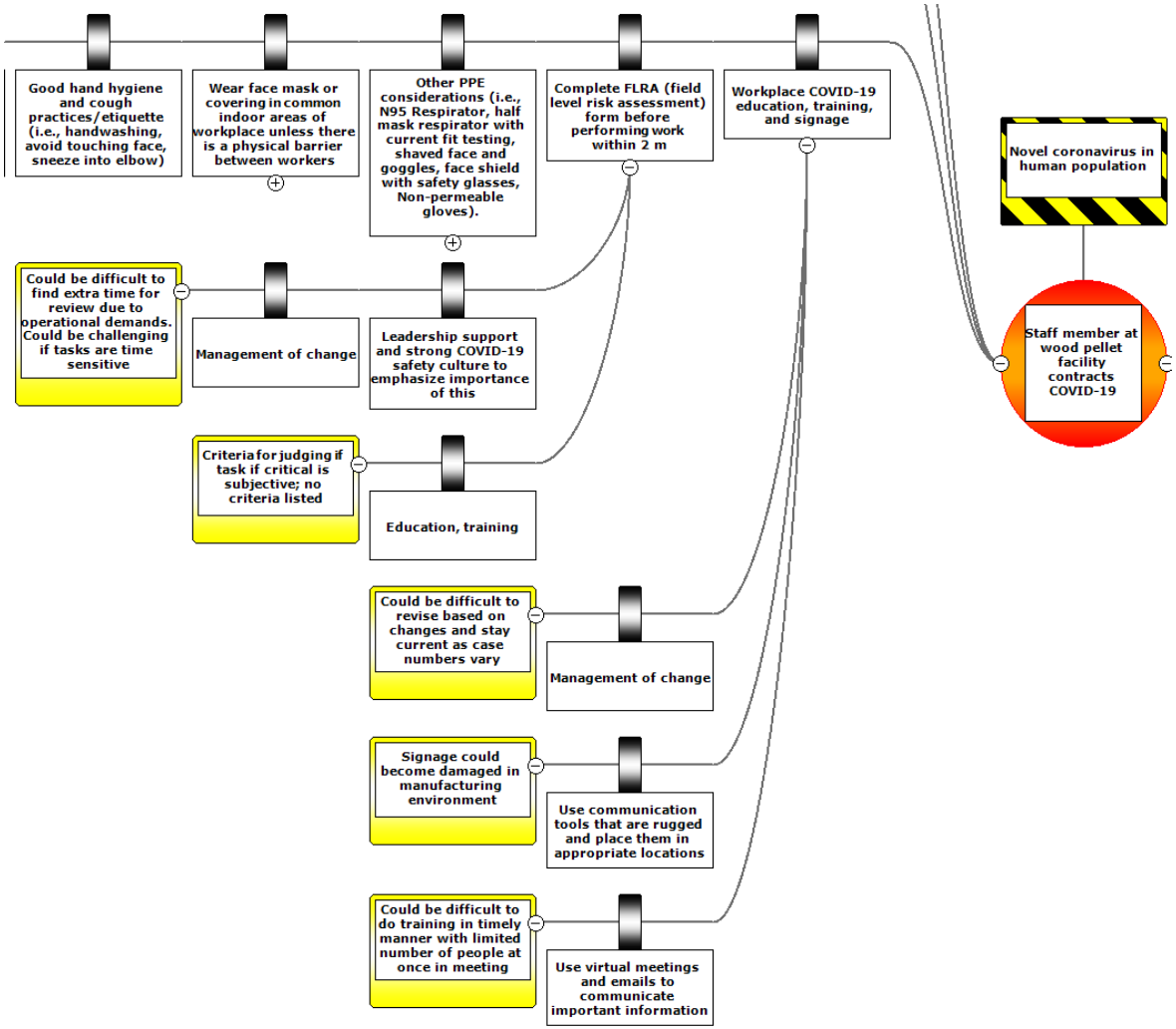

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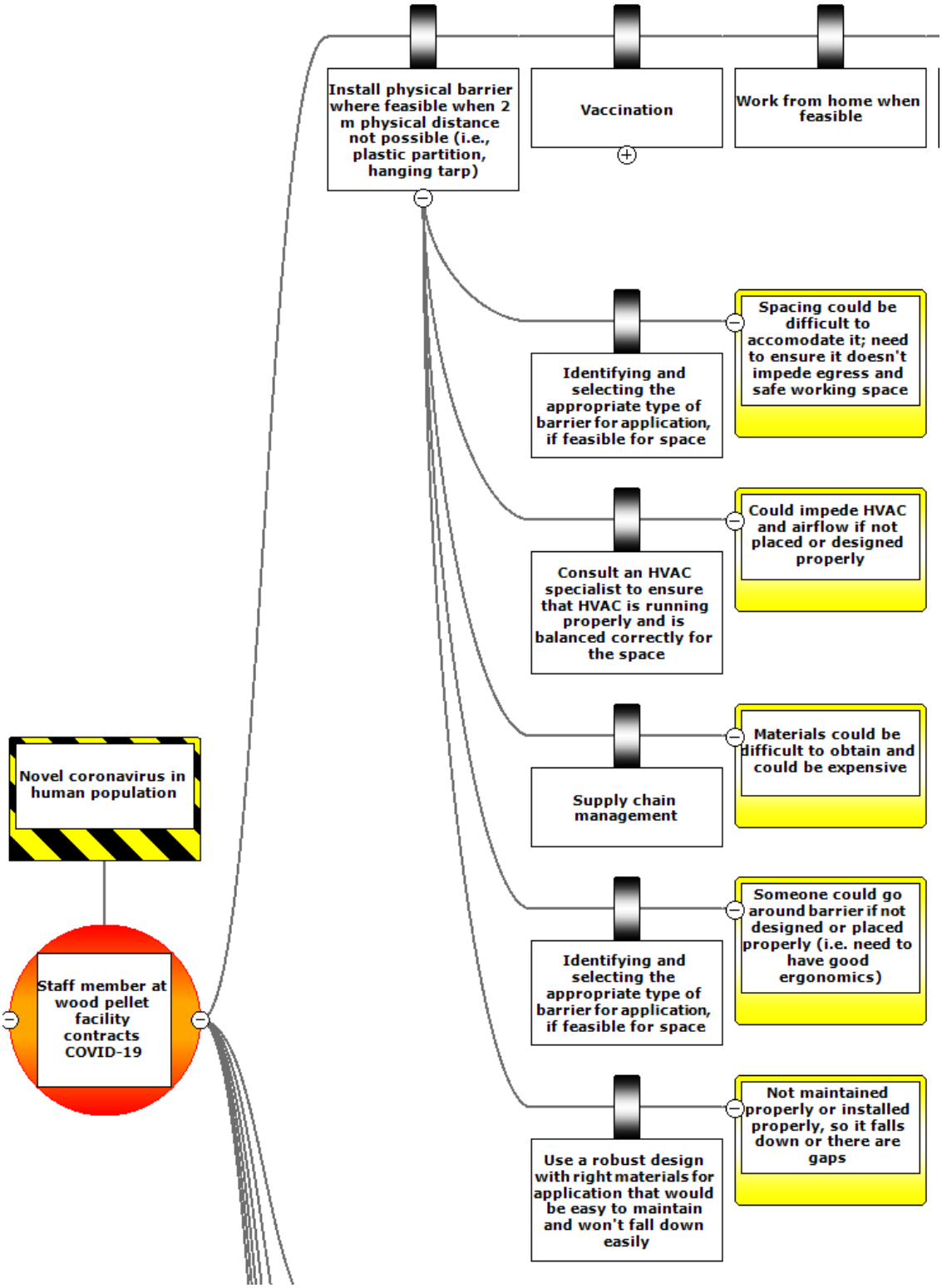

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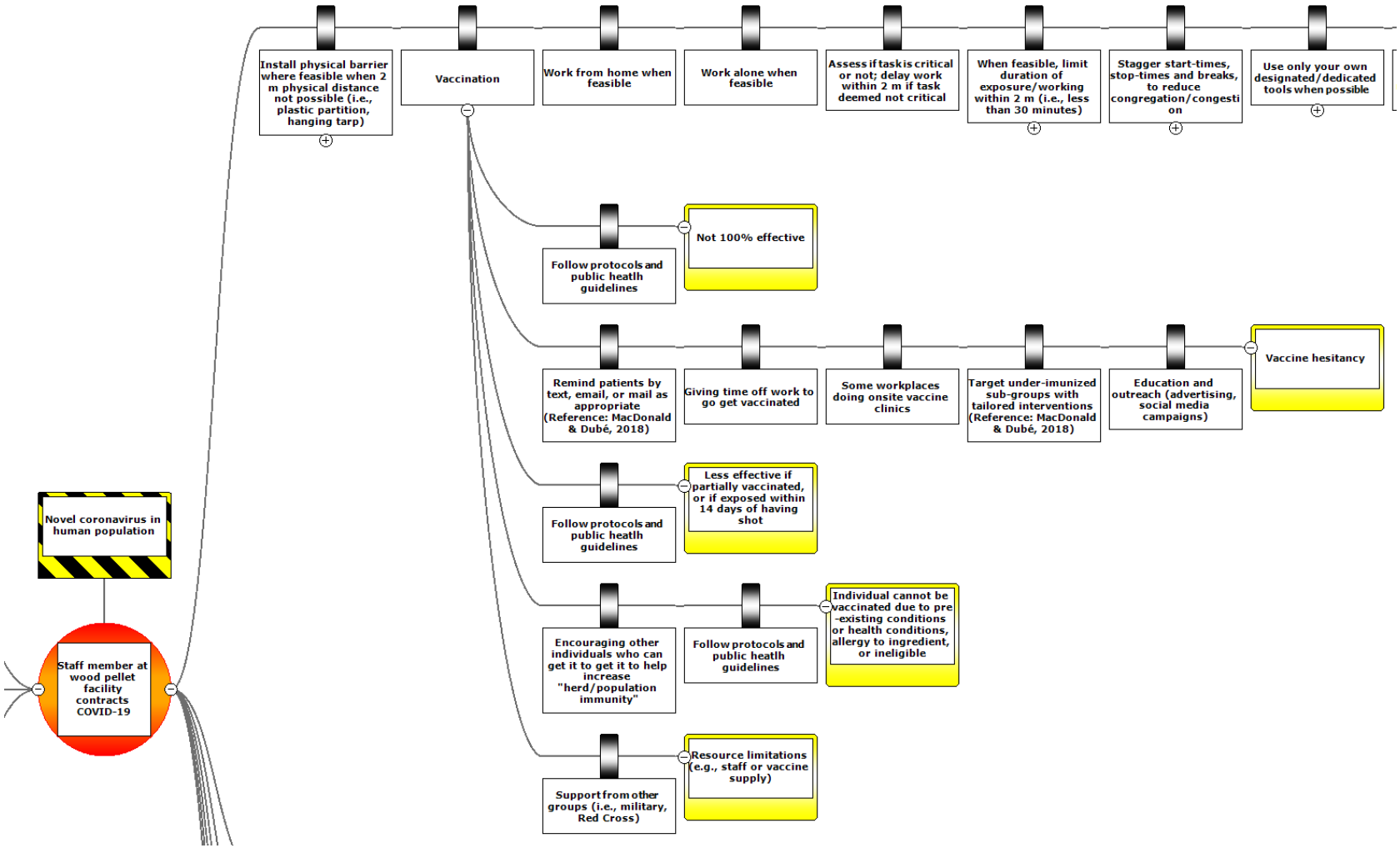

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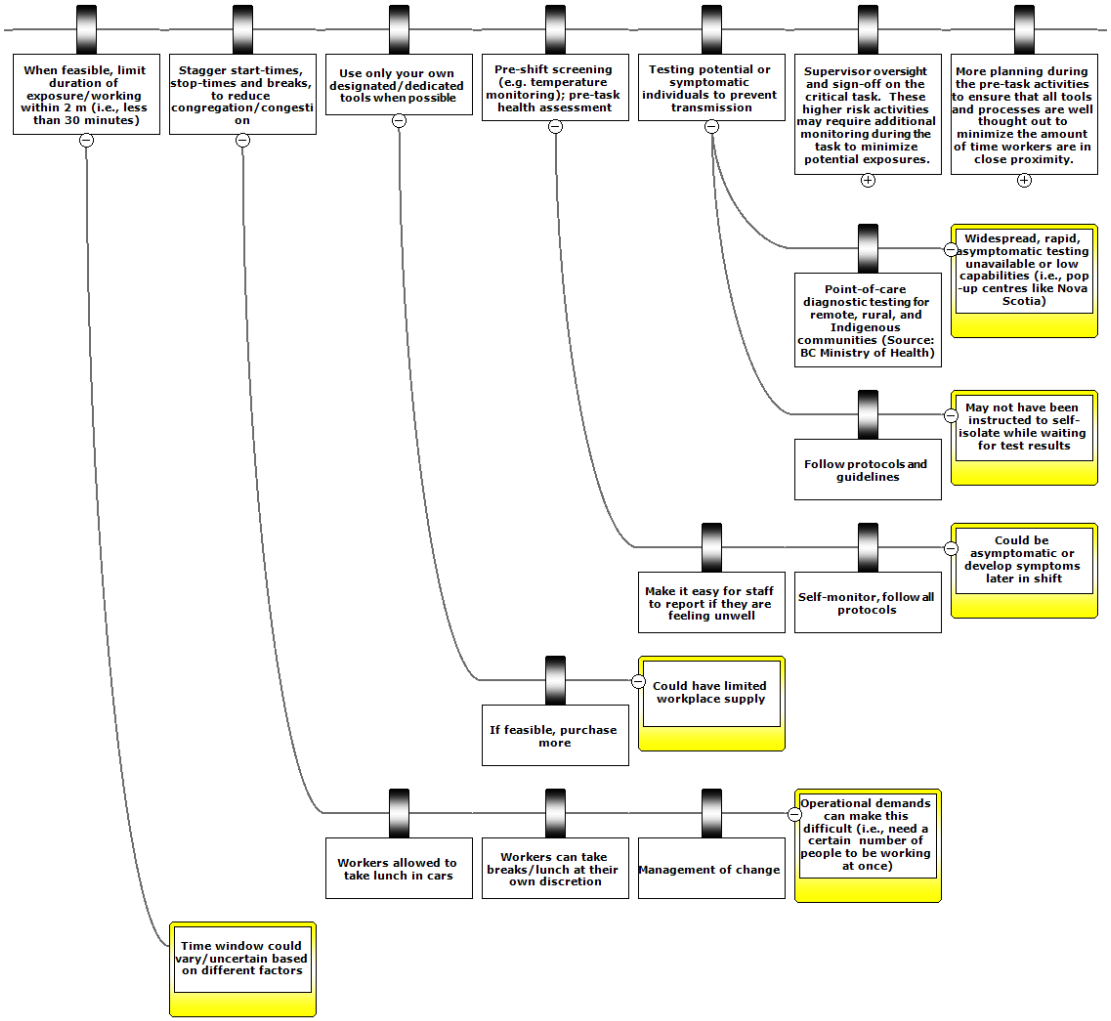

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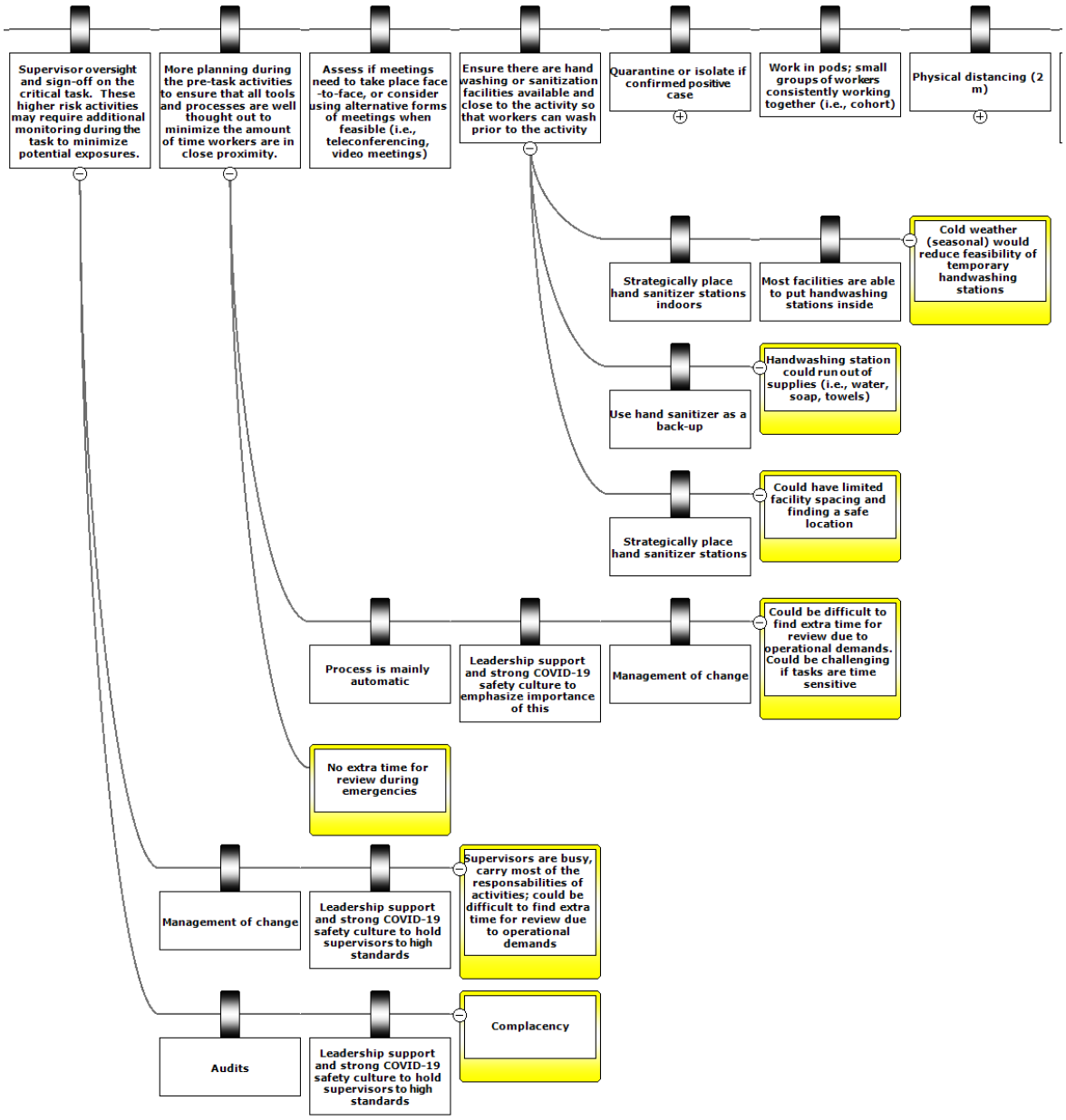

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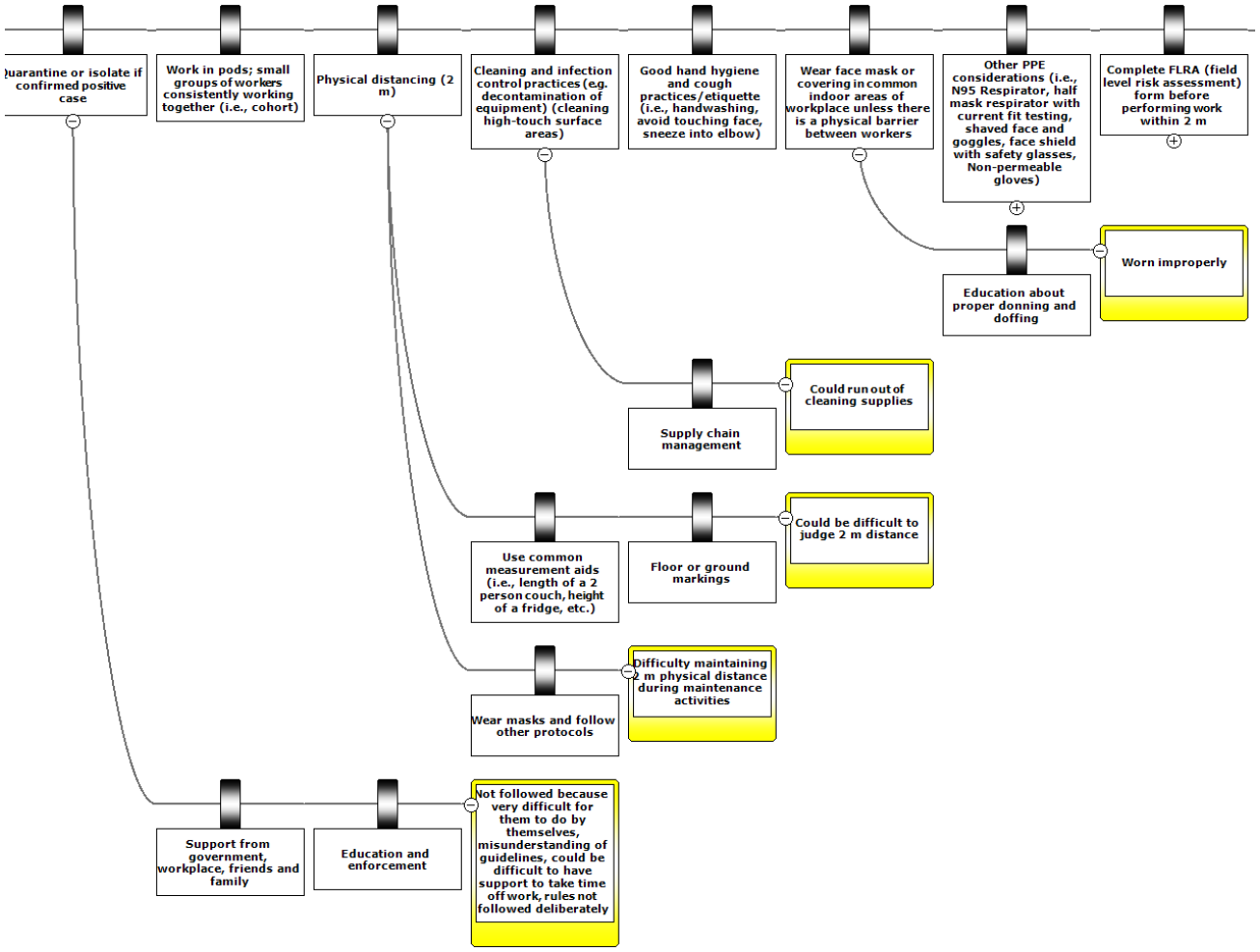

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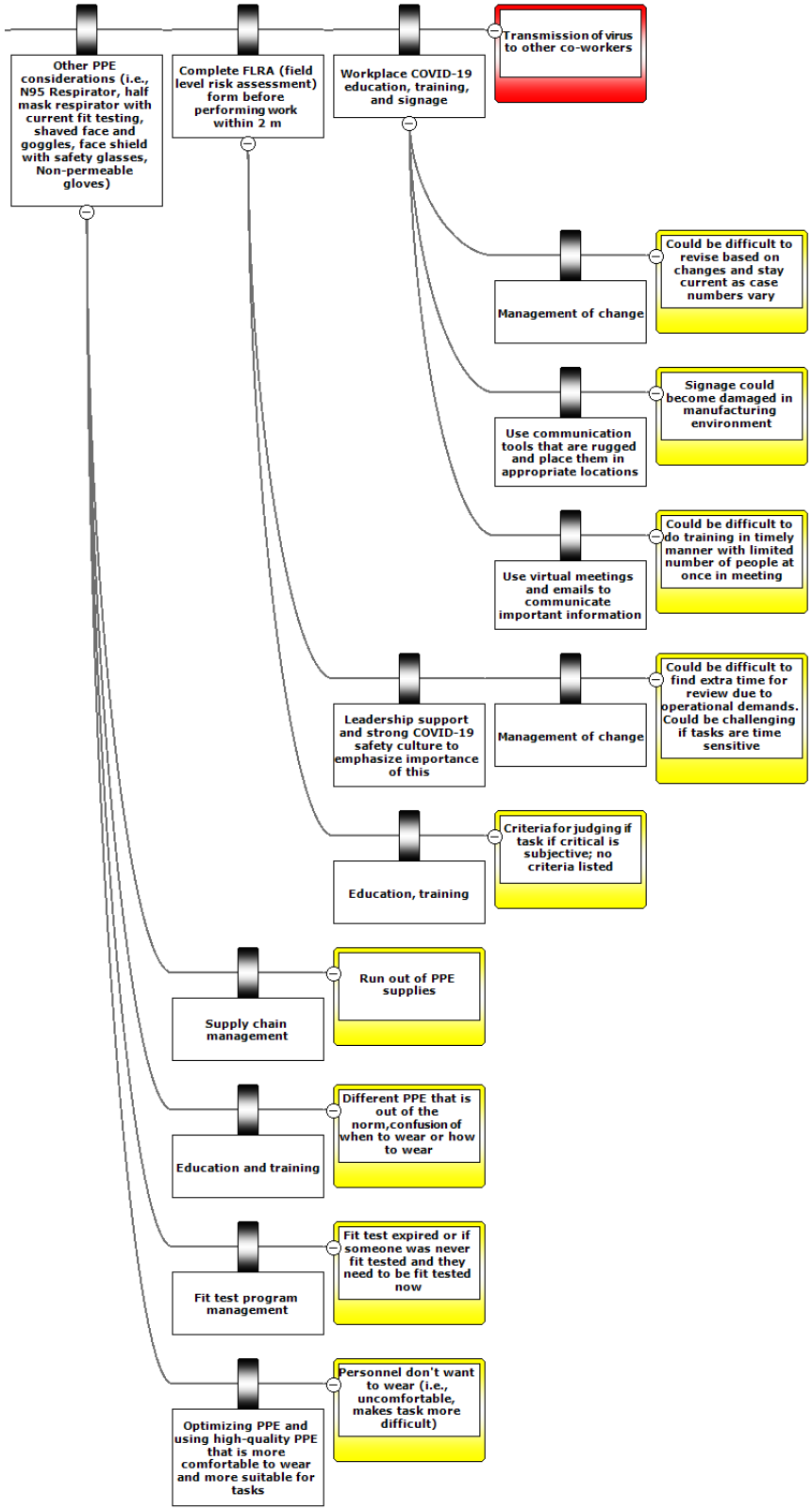

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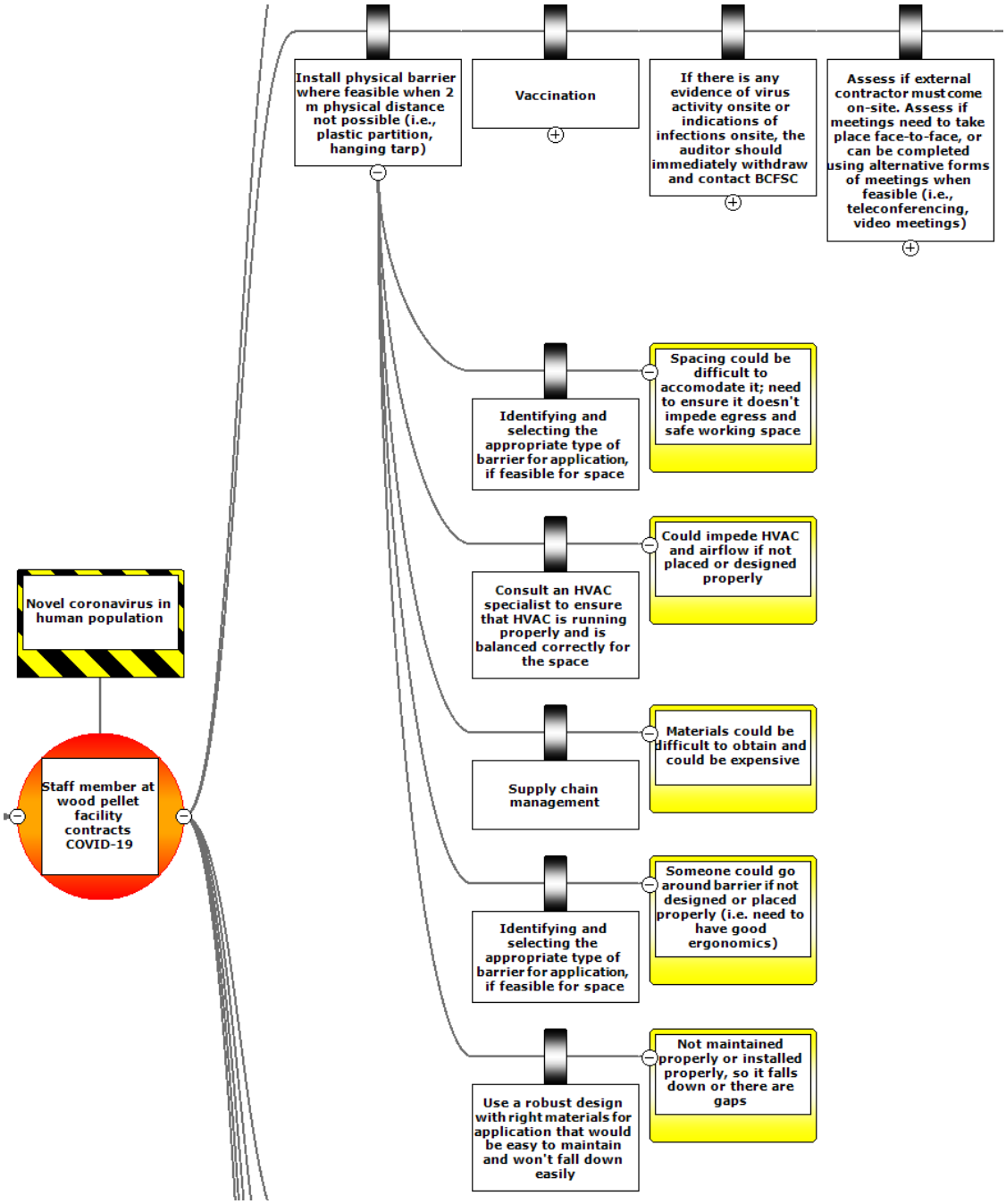

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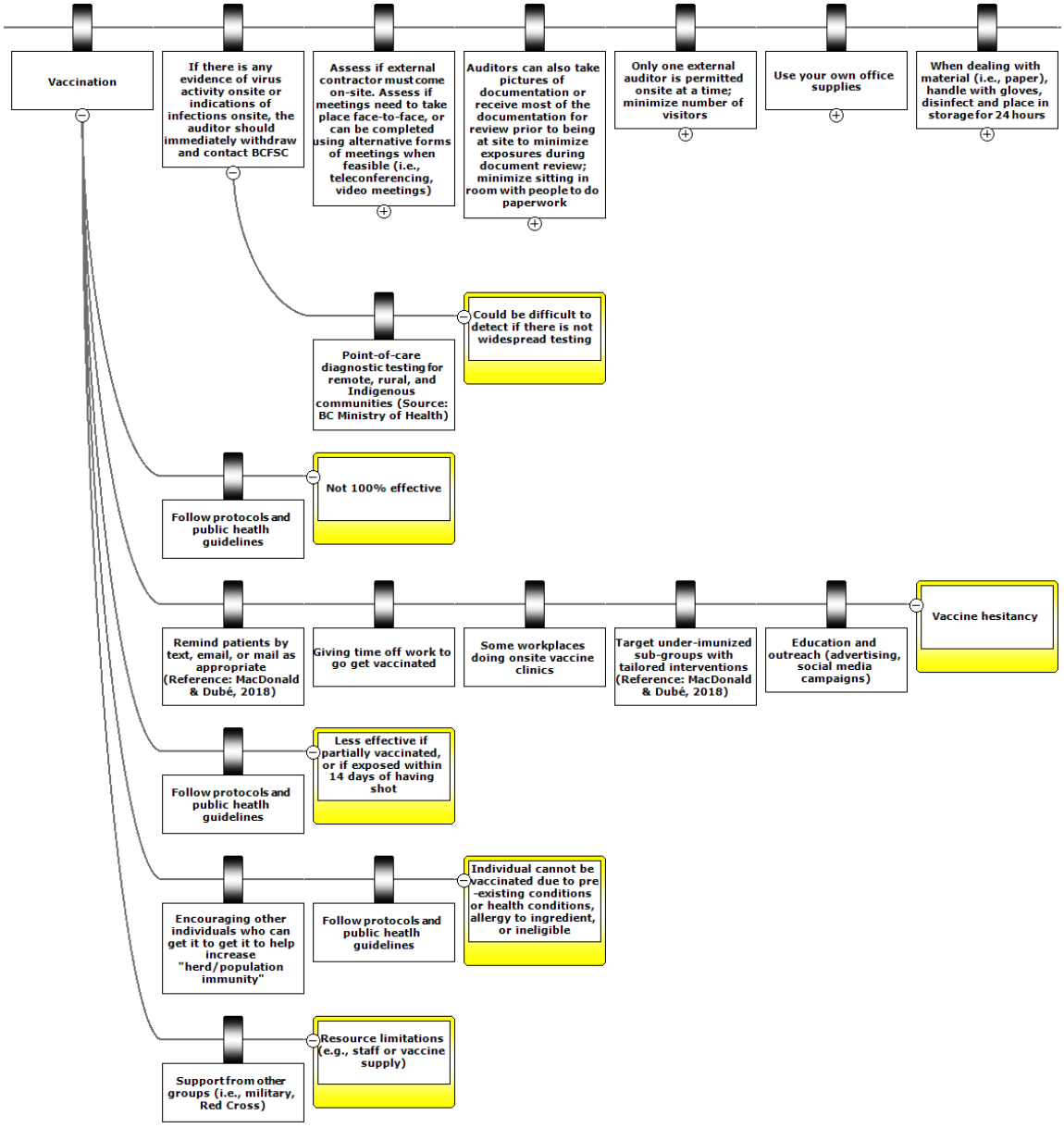

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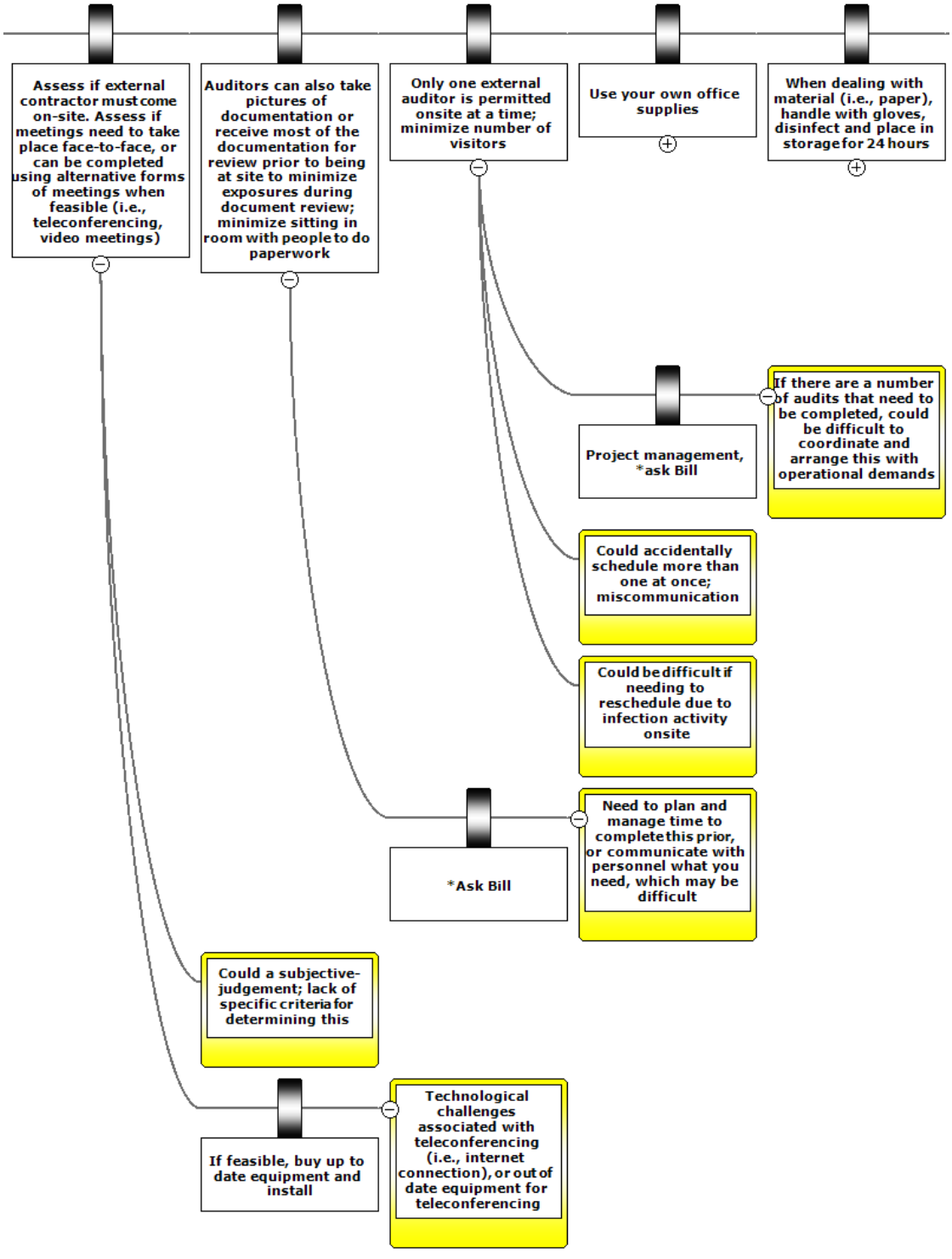

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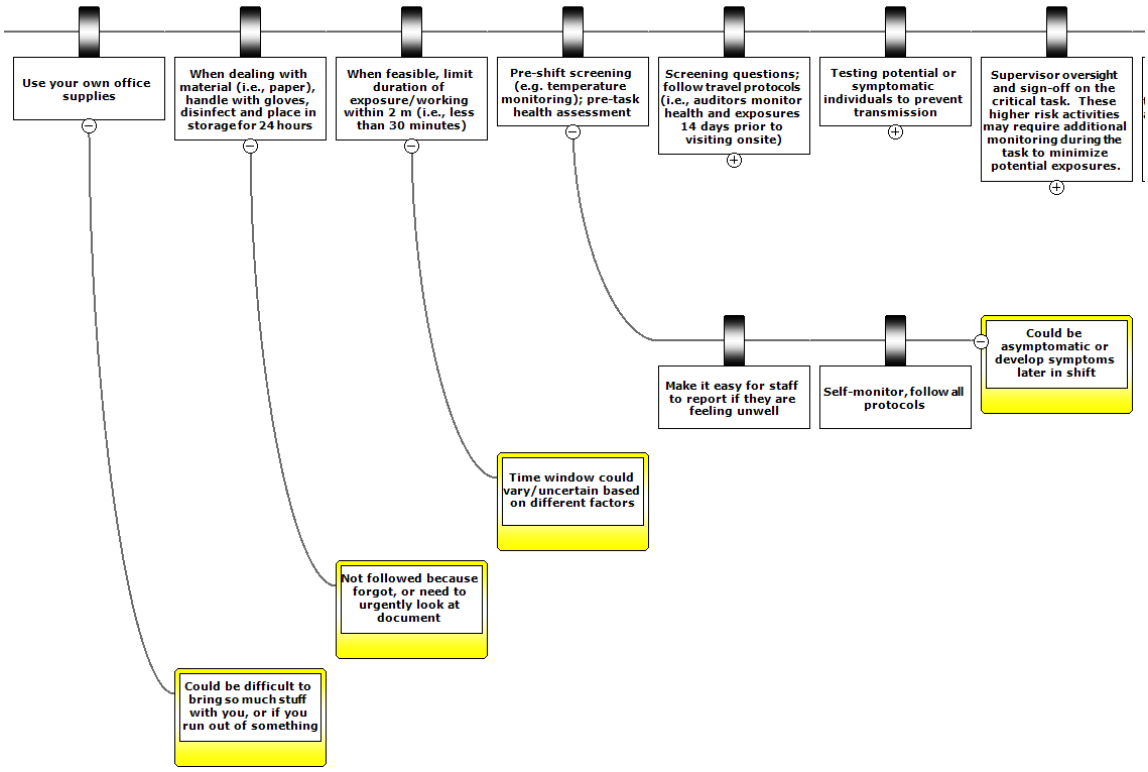

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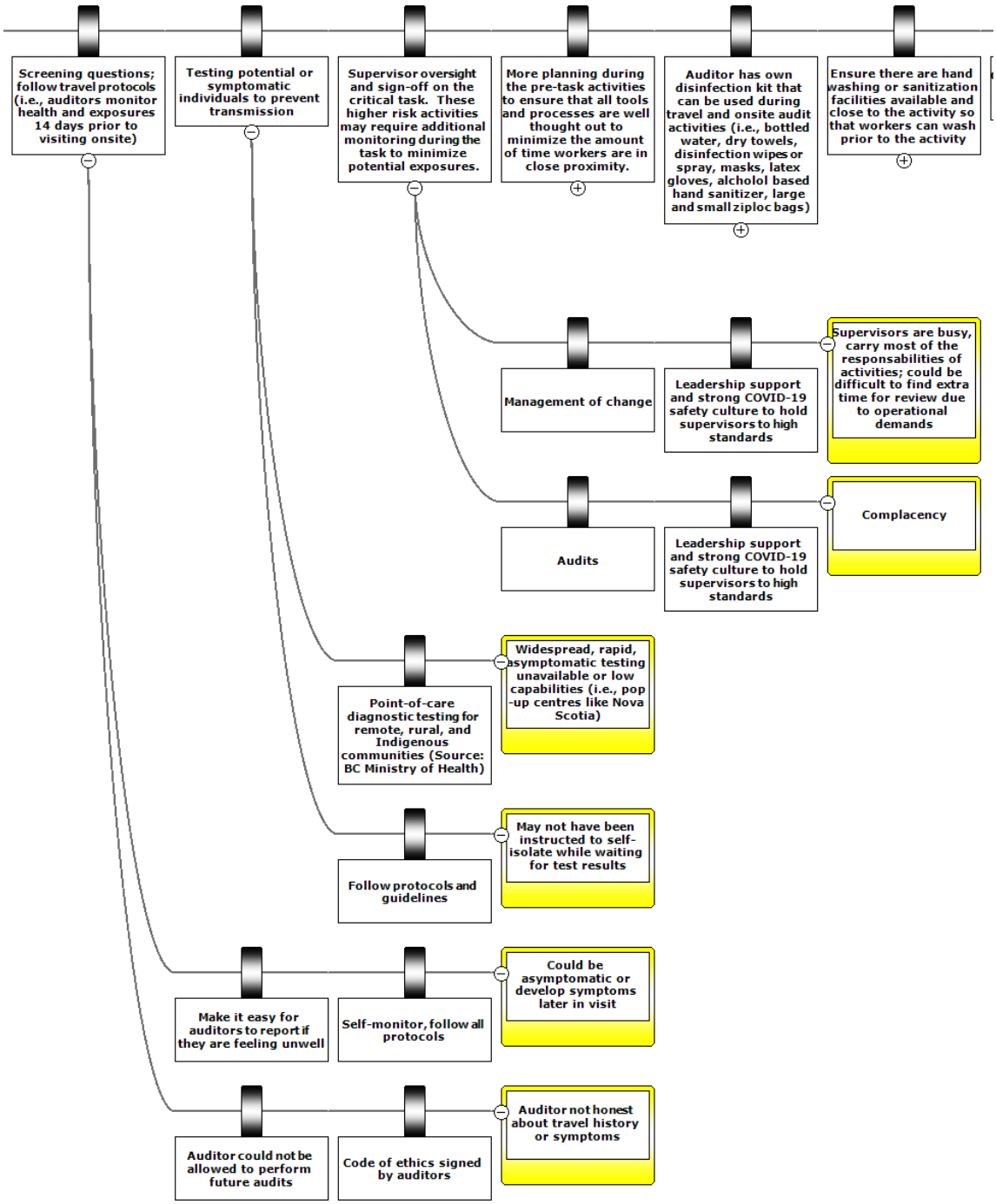

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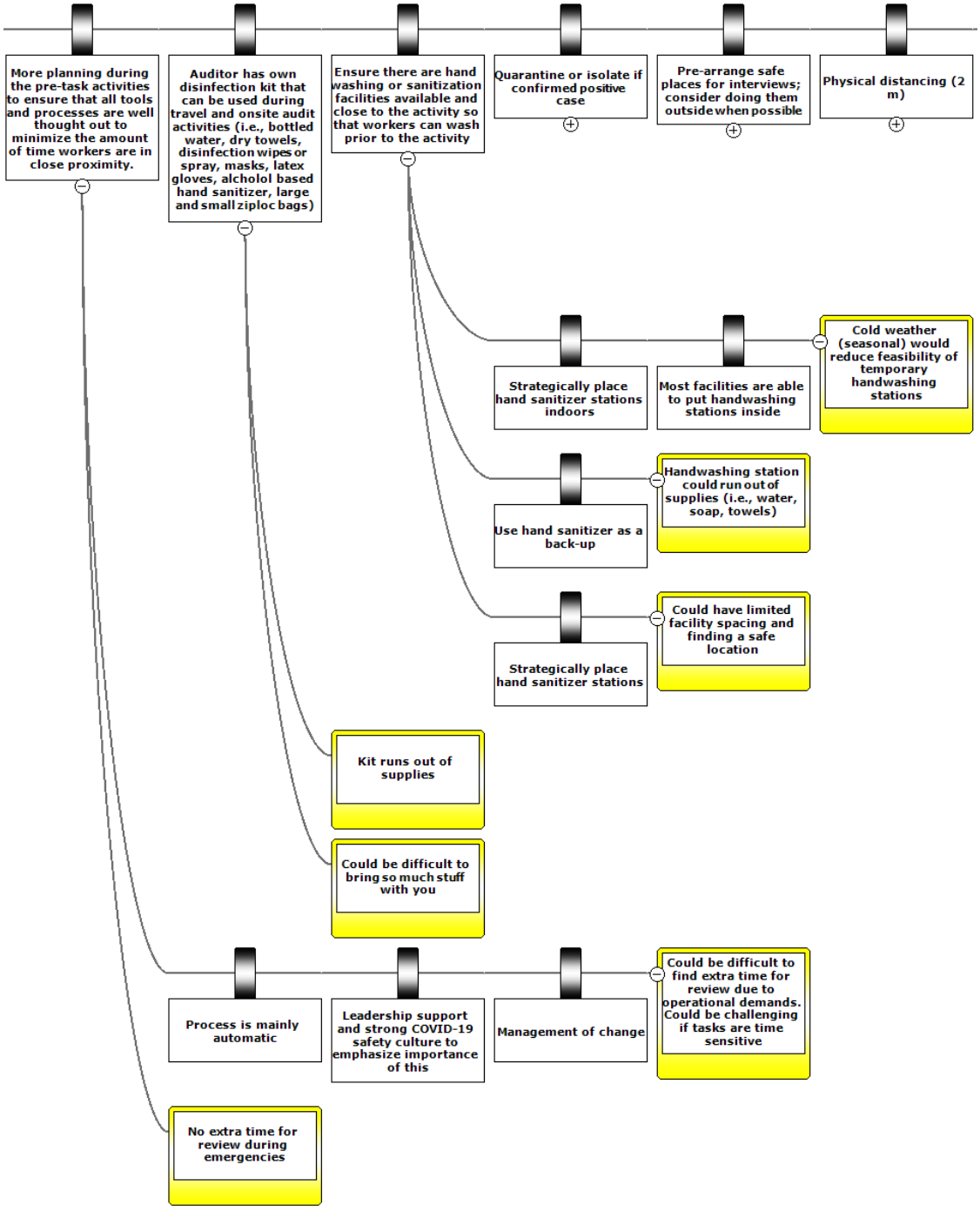

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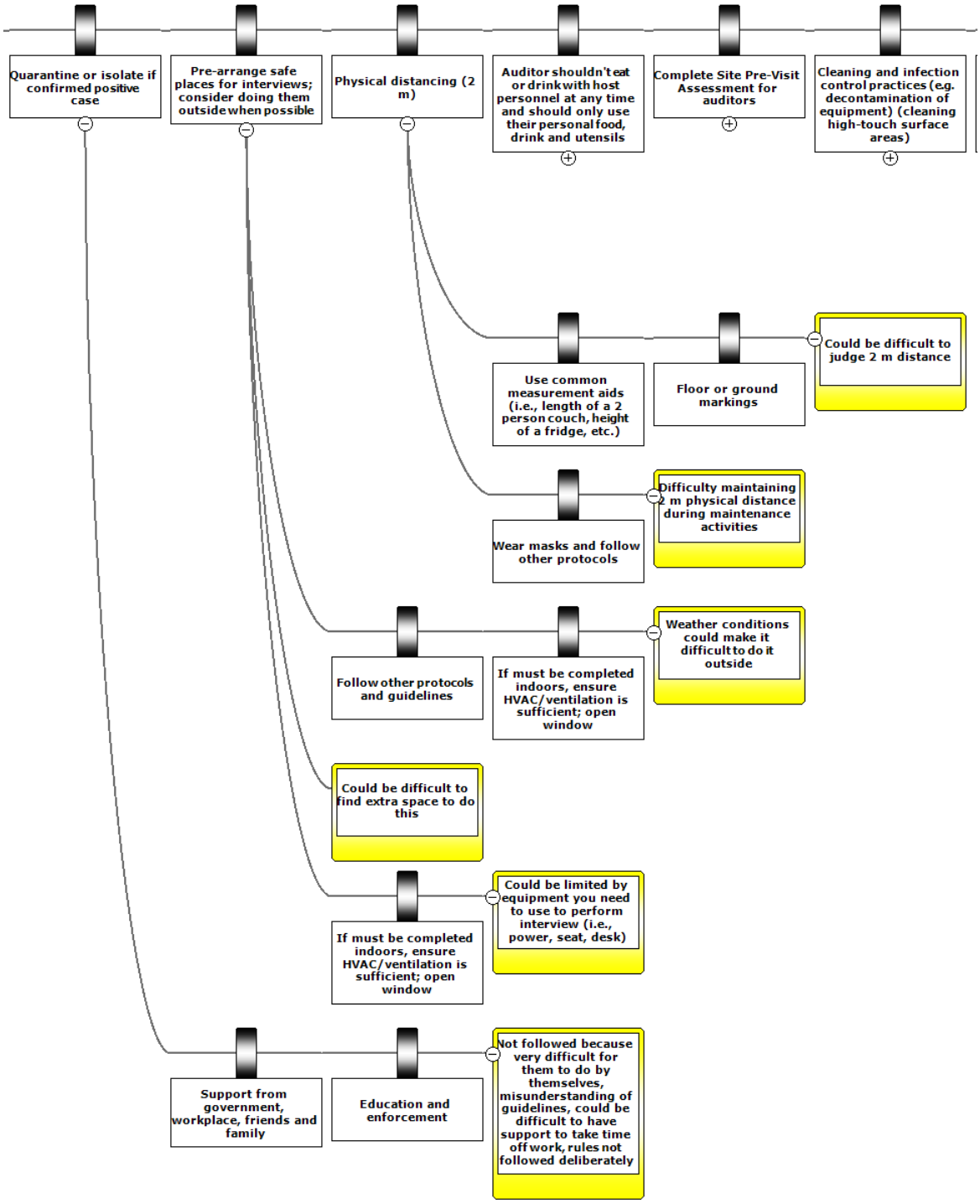
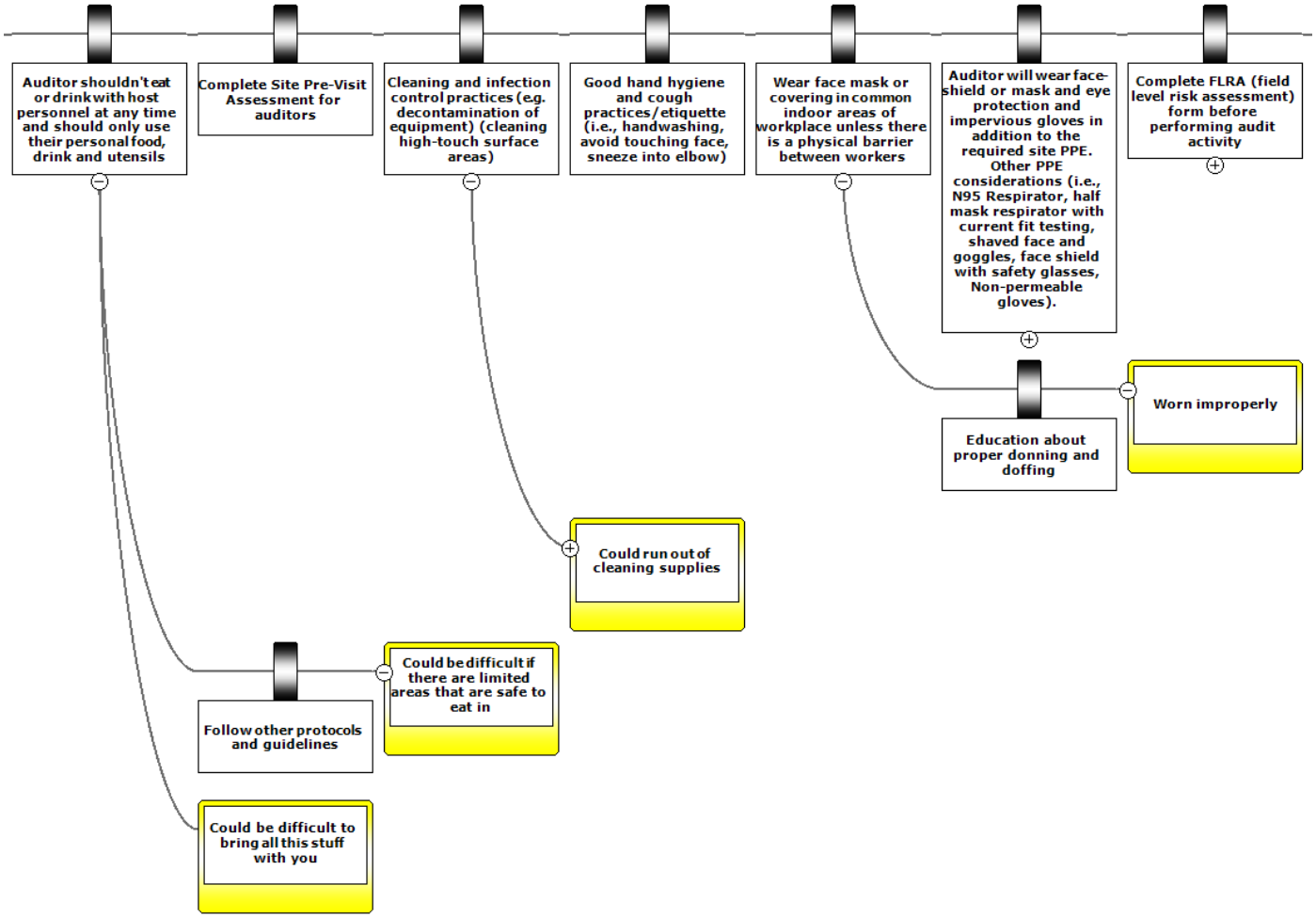


Figure B-31. BCFSC wood pellet facility COVID-19 bow tie diagram part 31



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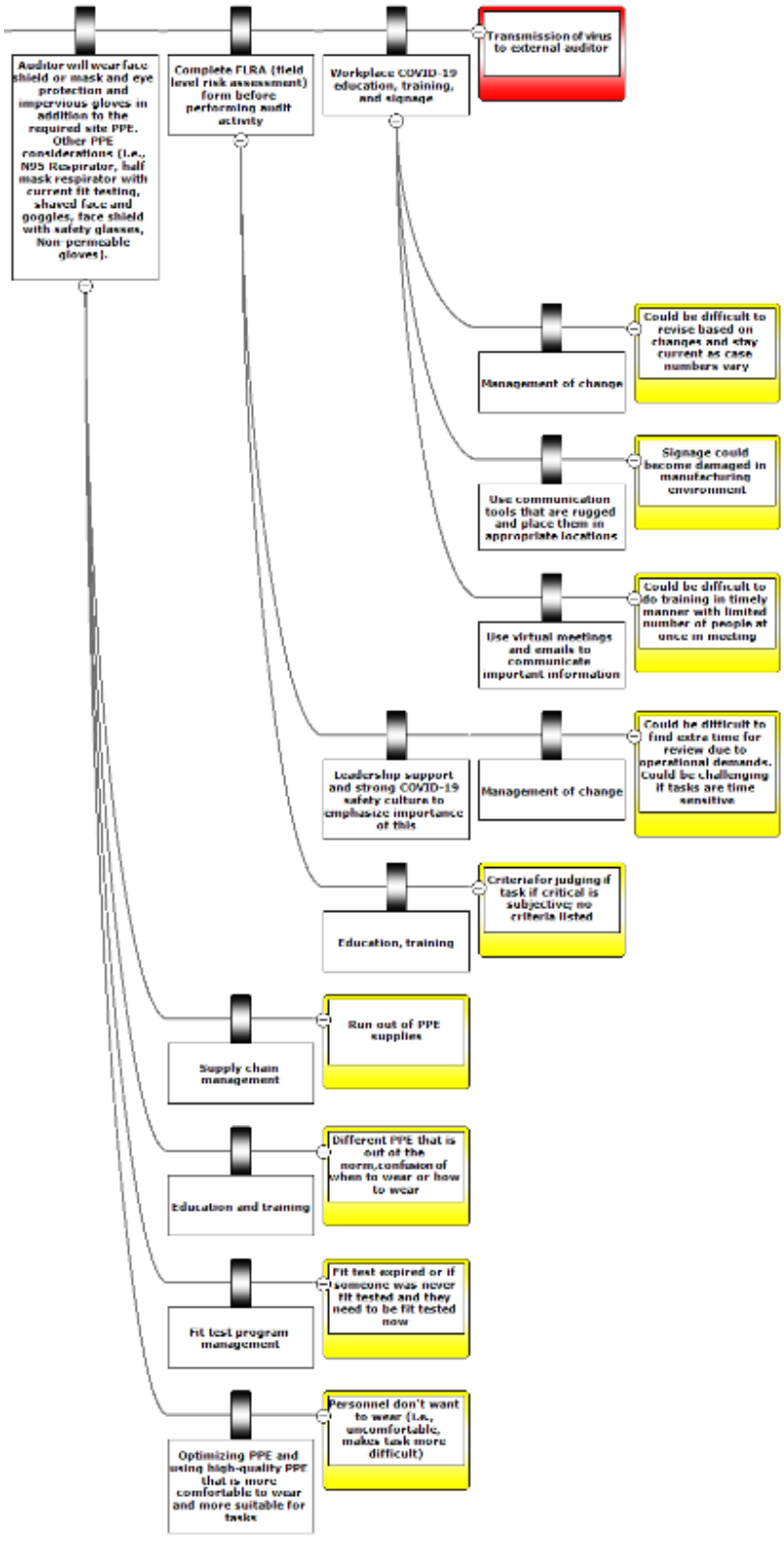

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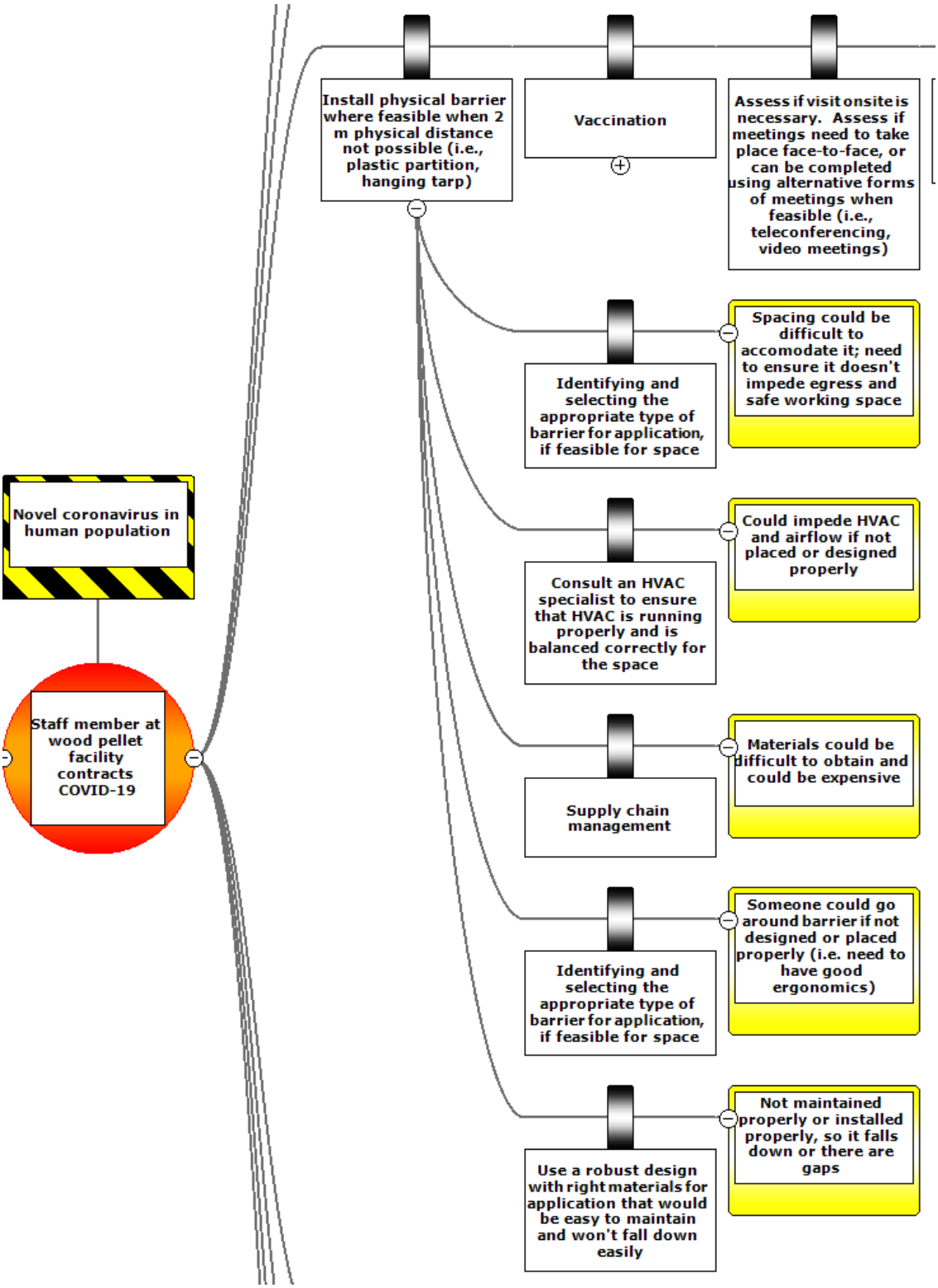

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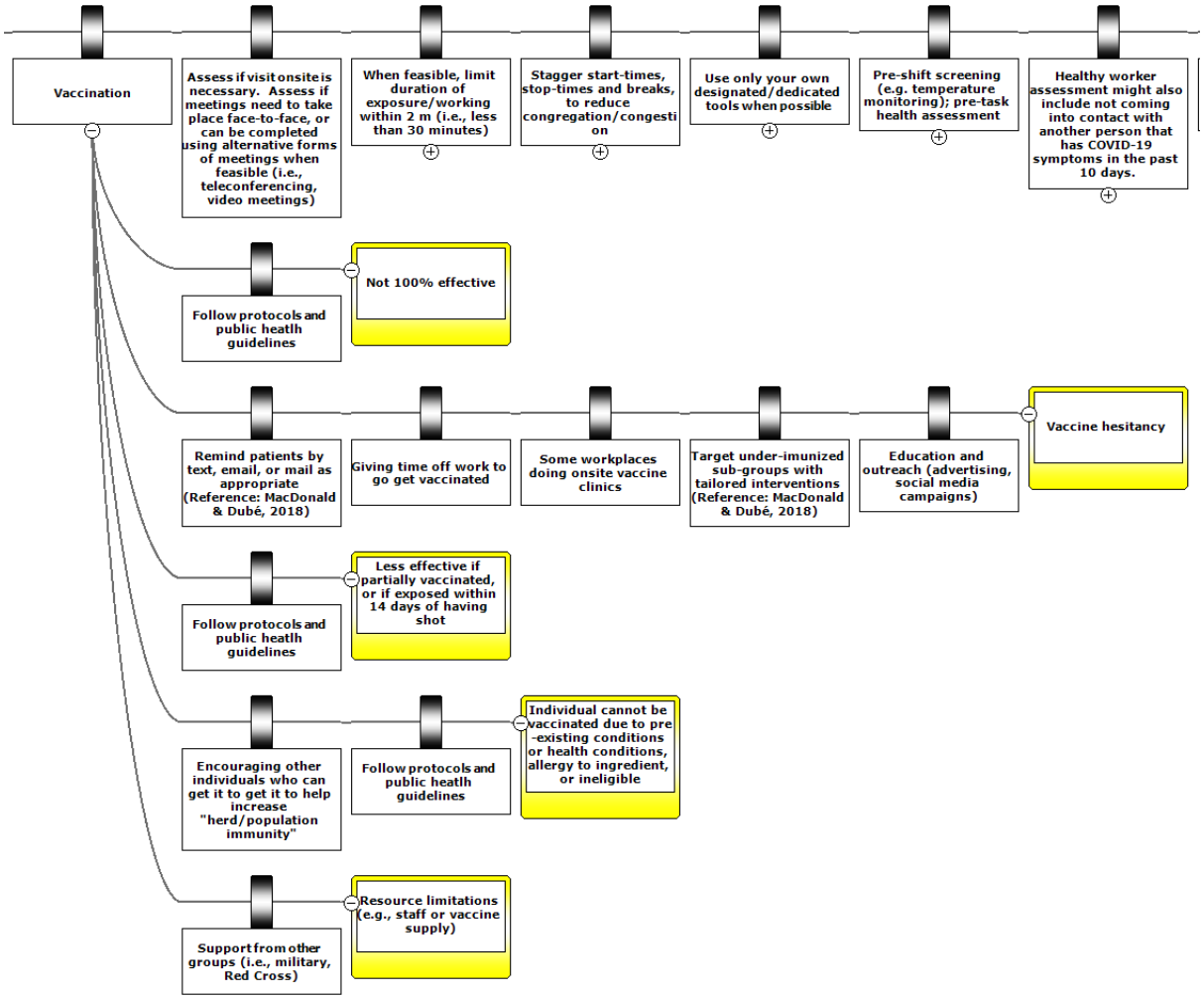

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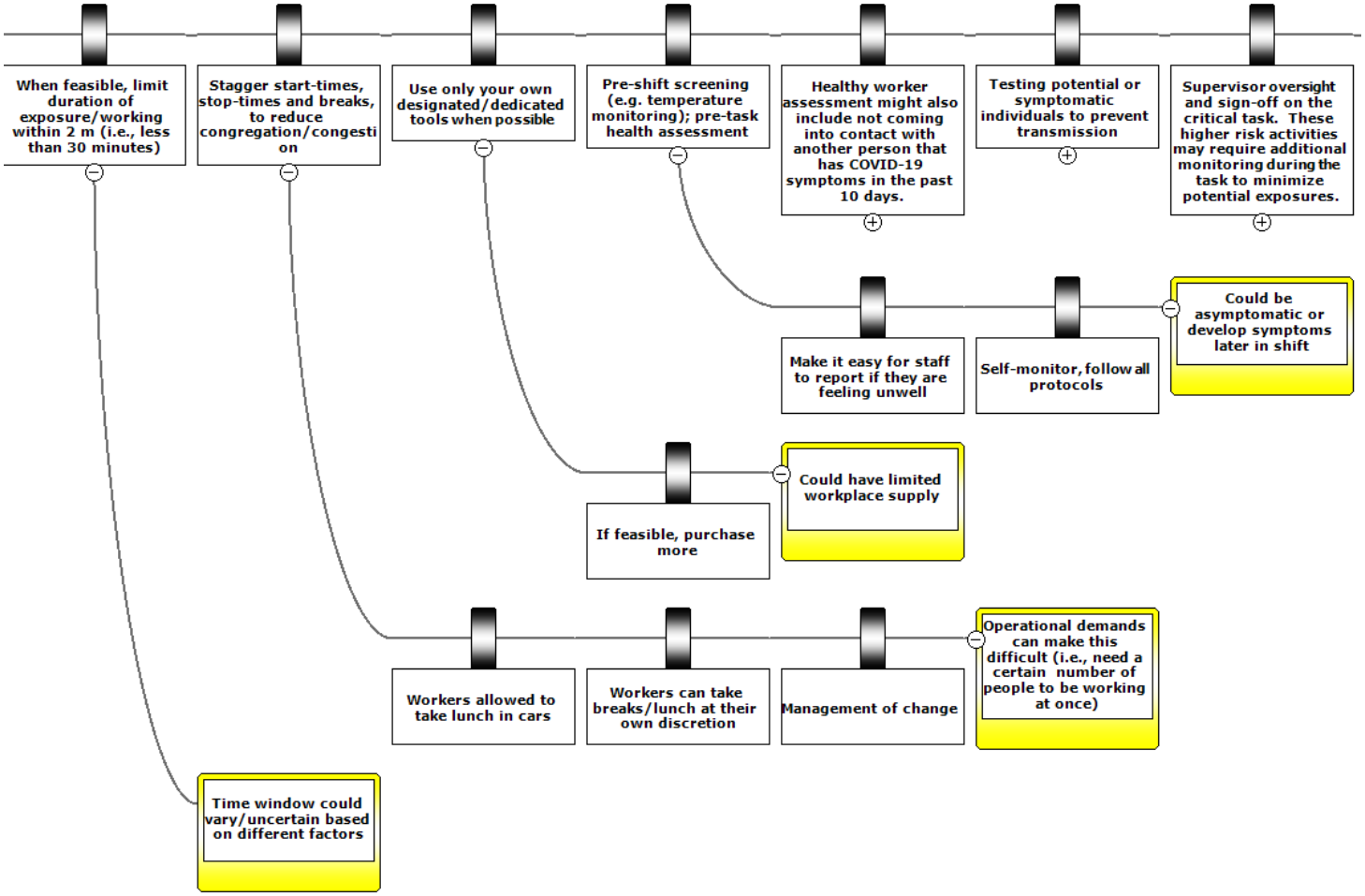

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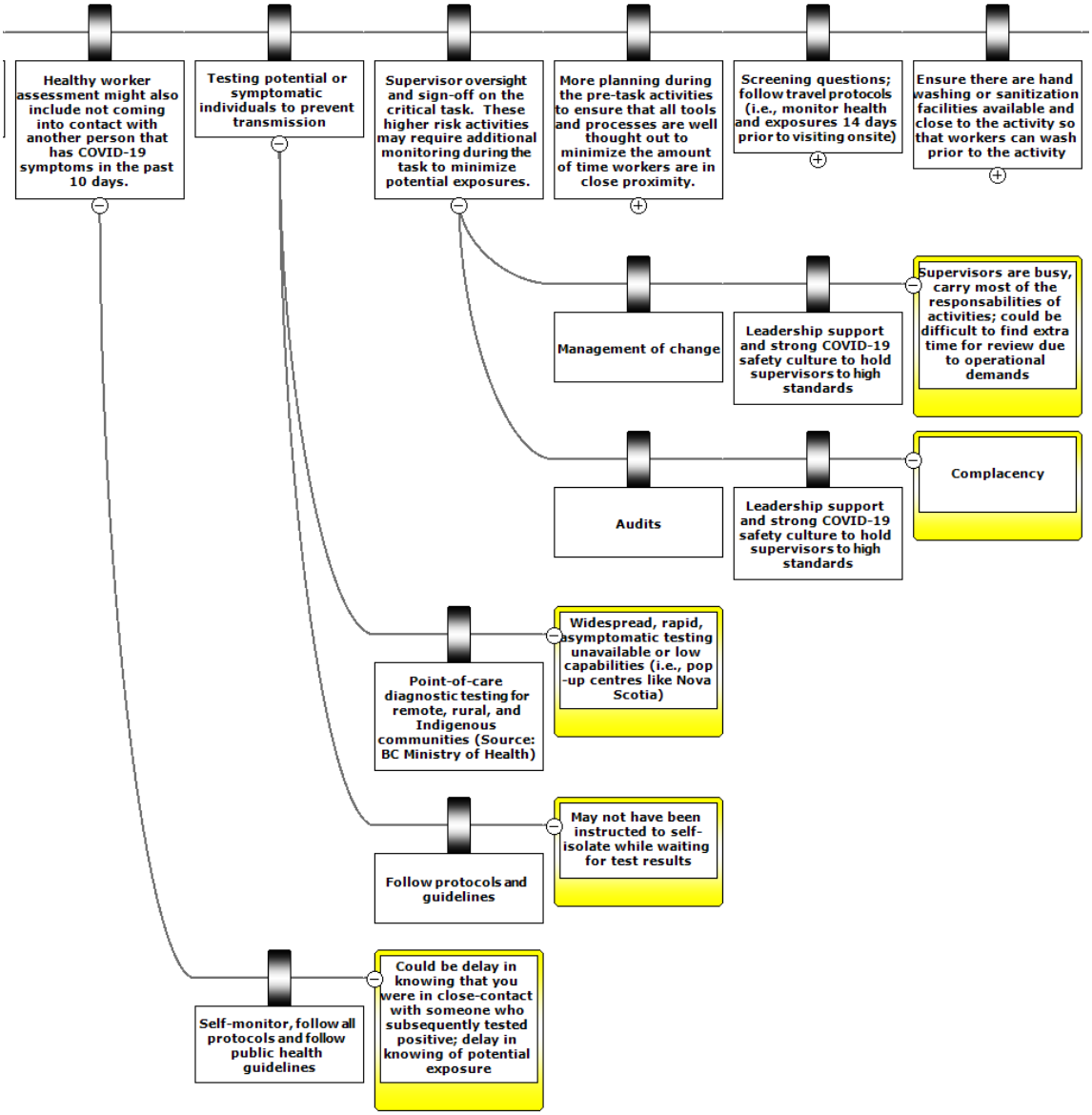

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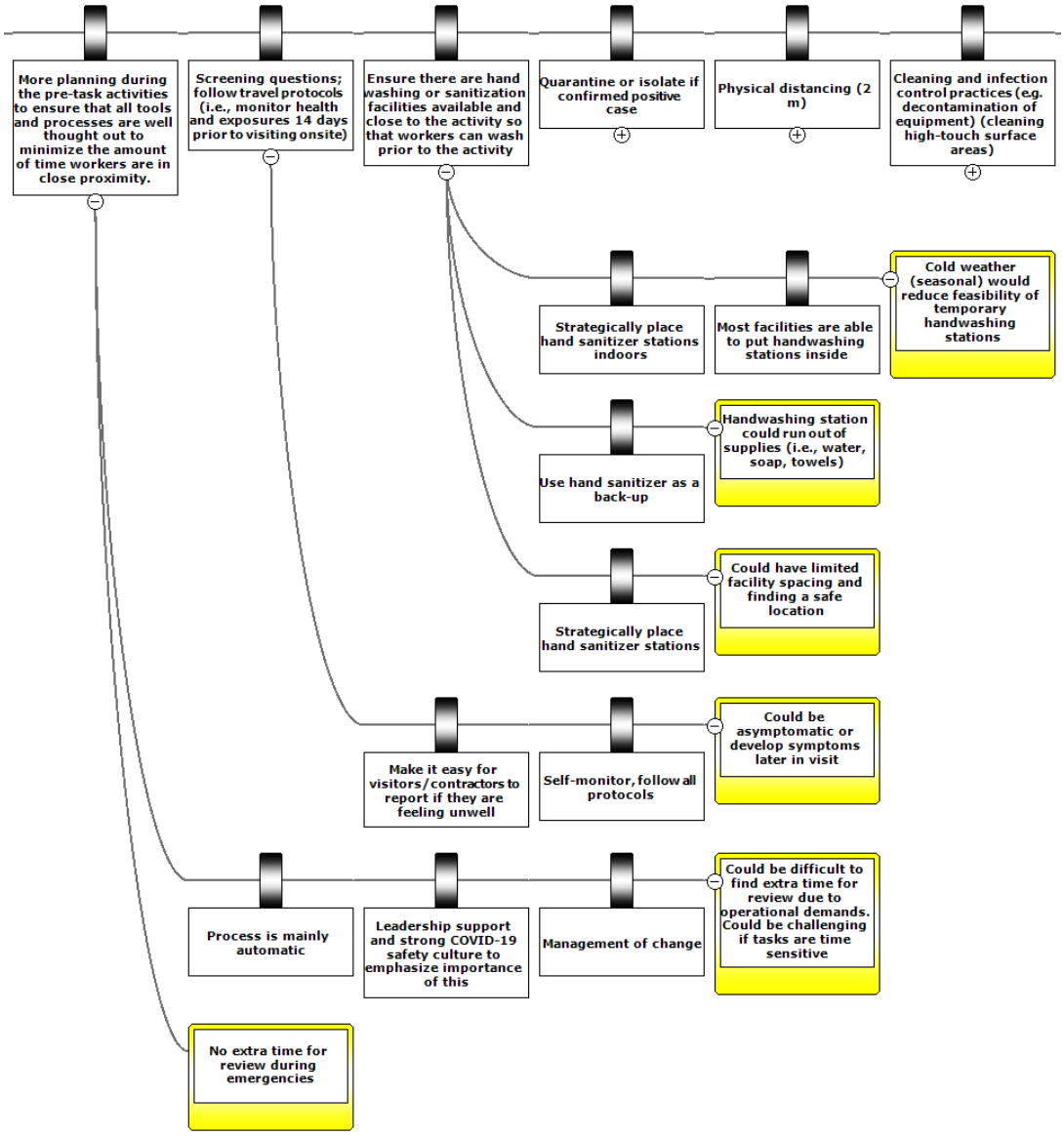

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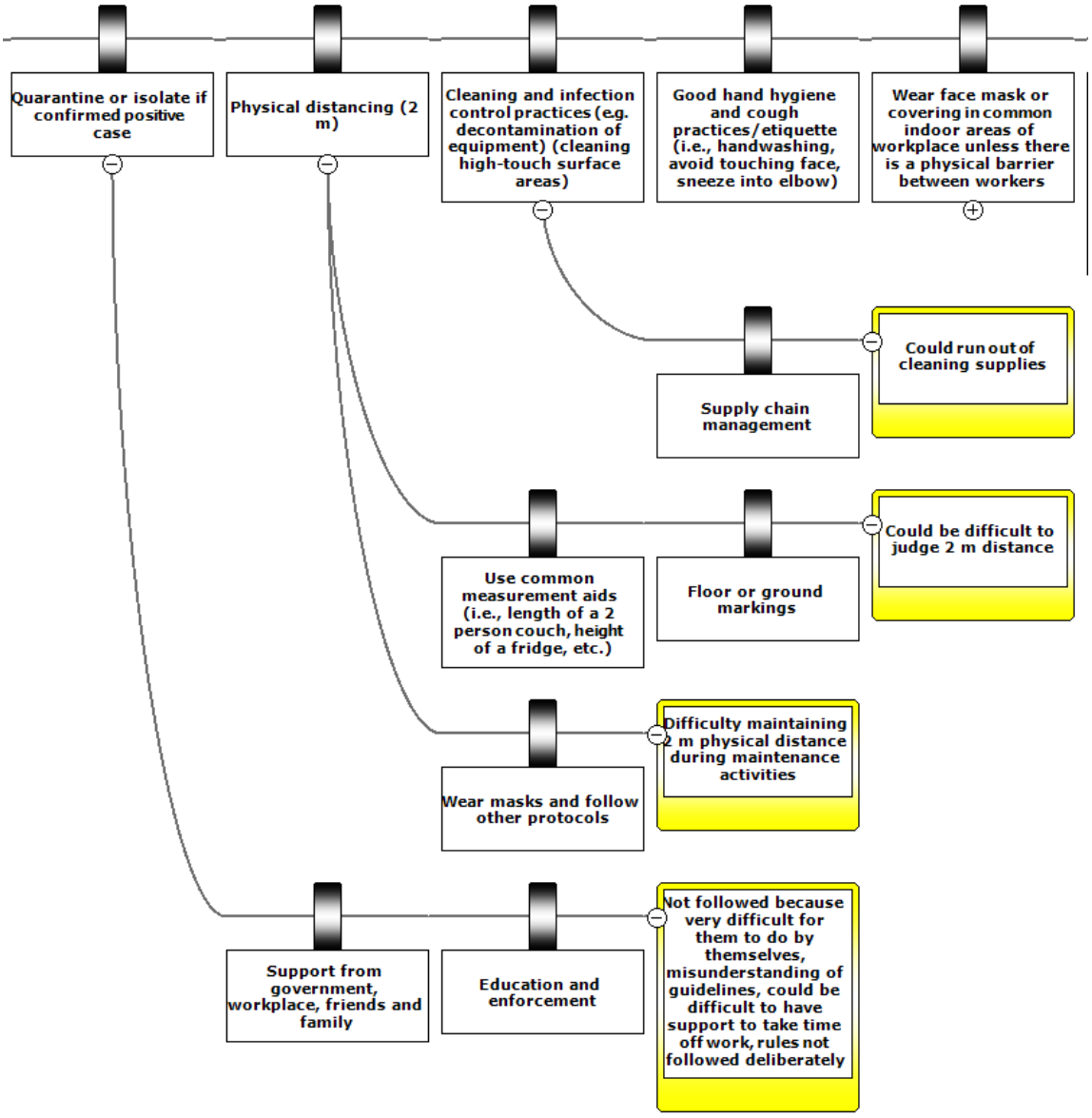

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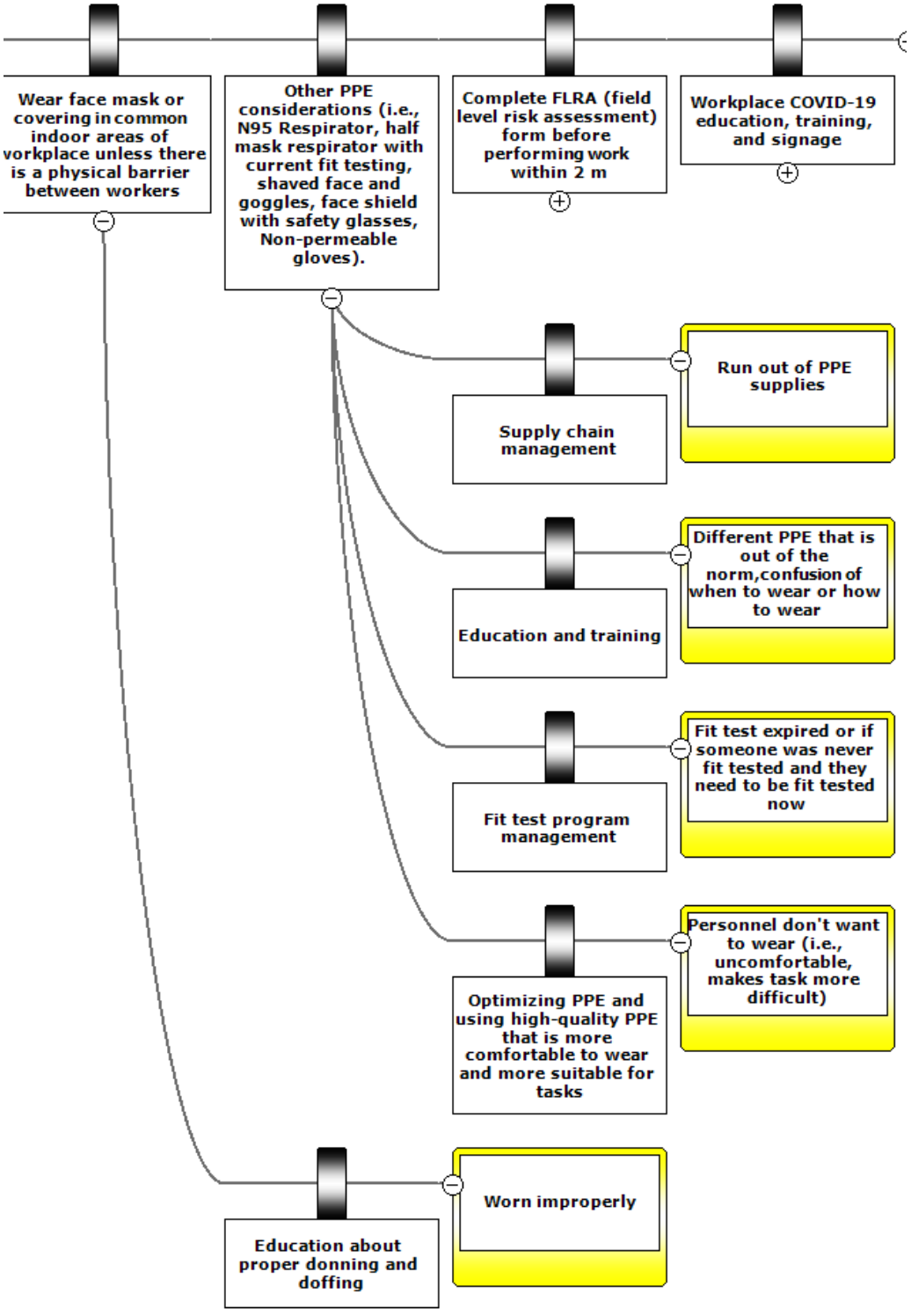

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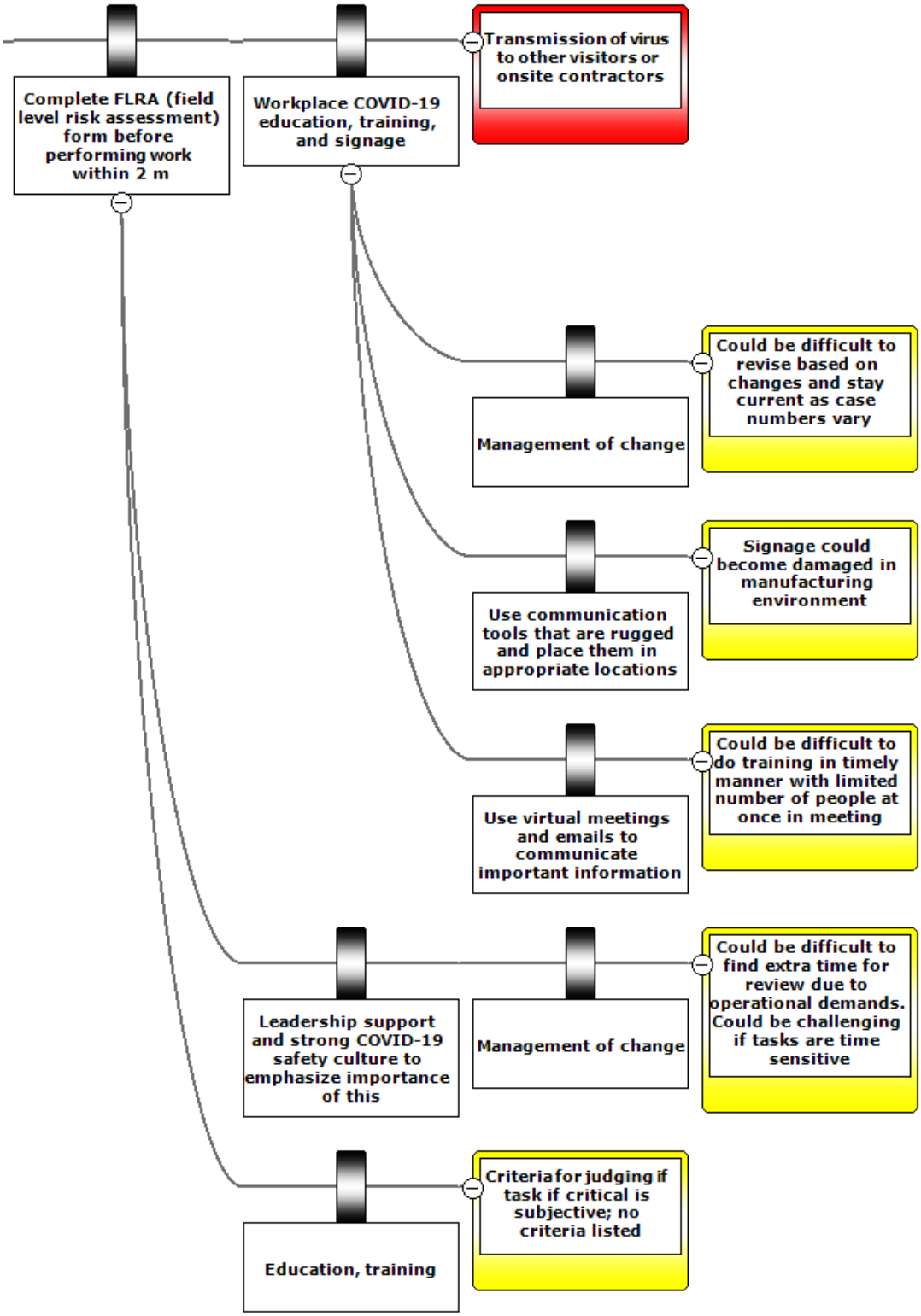

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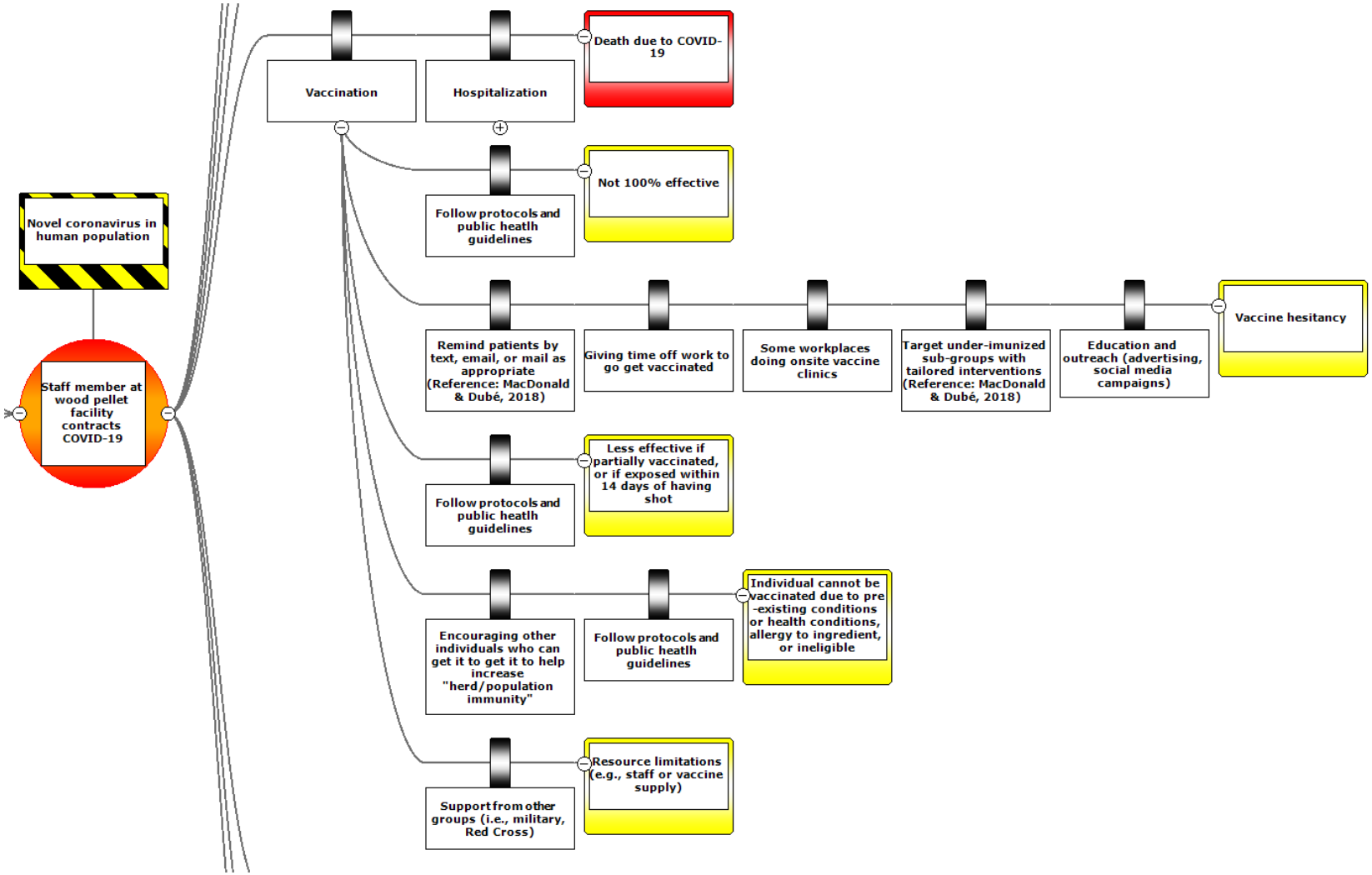

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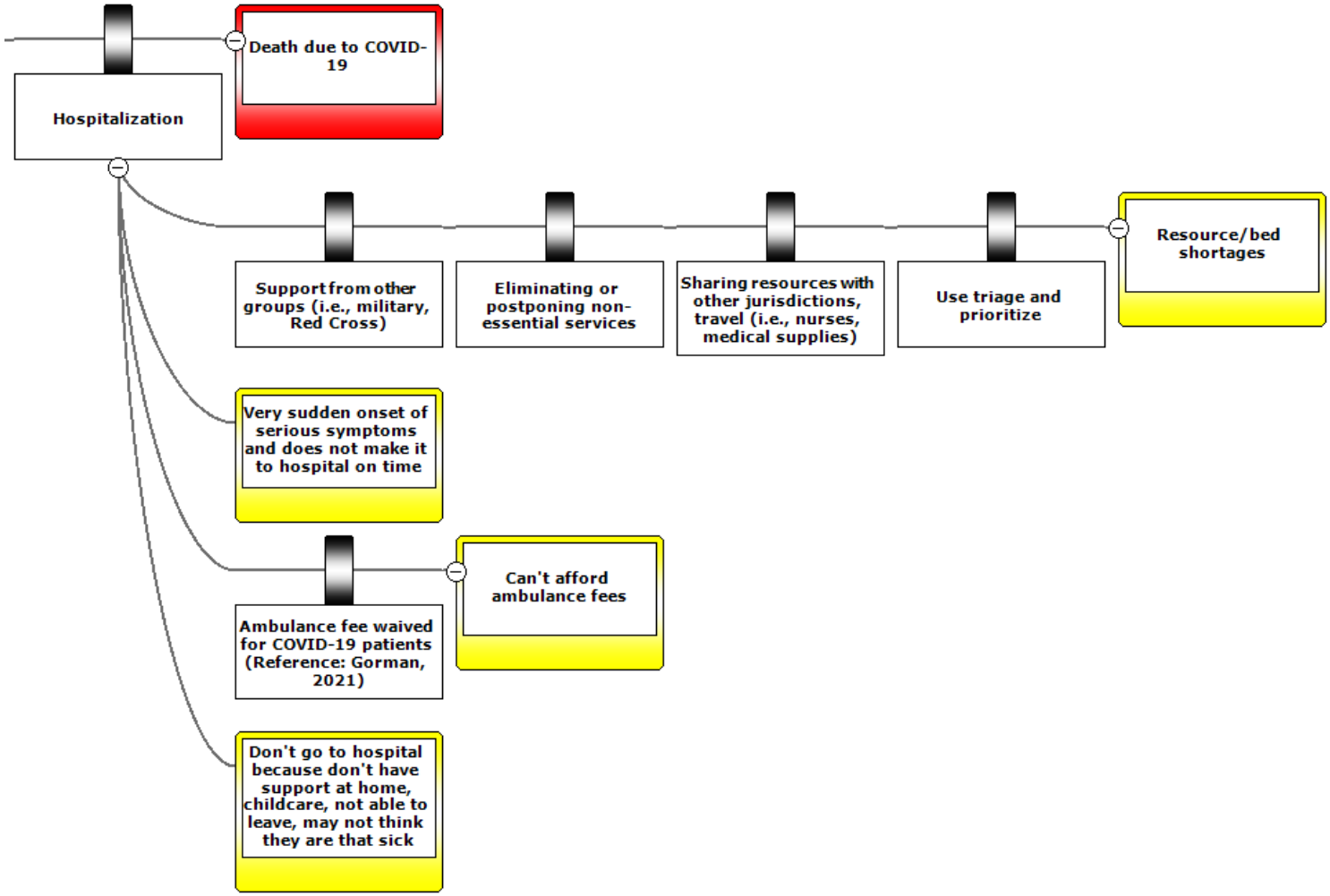

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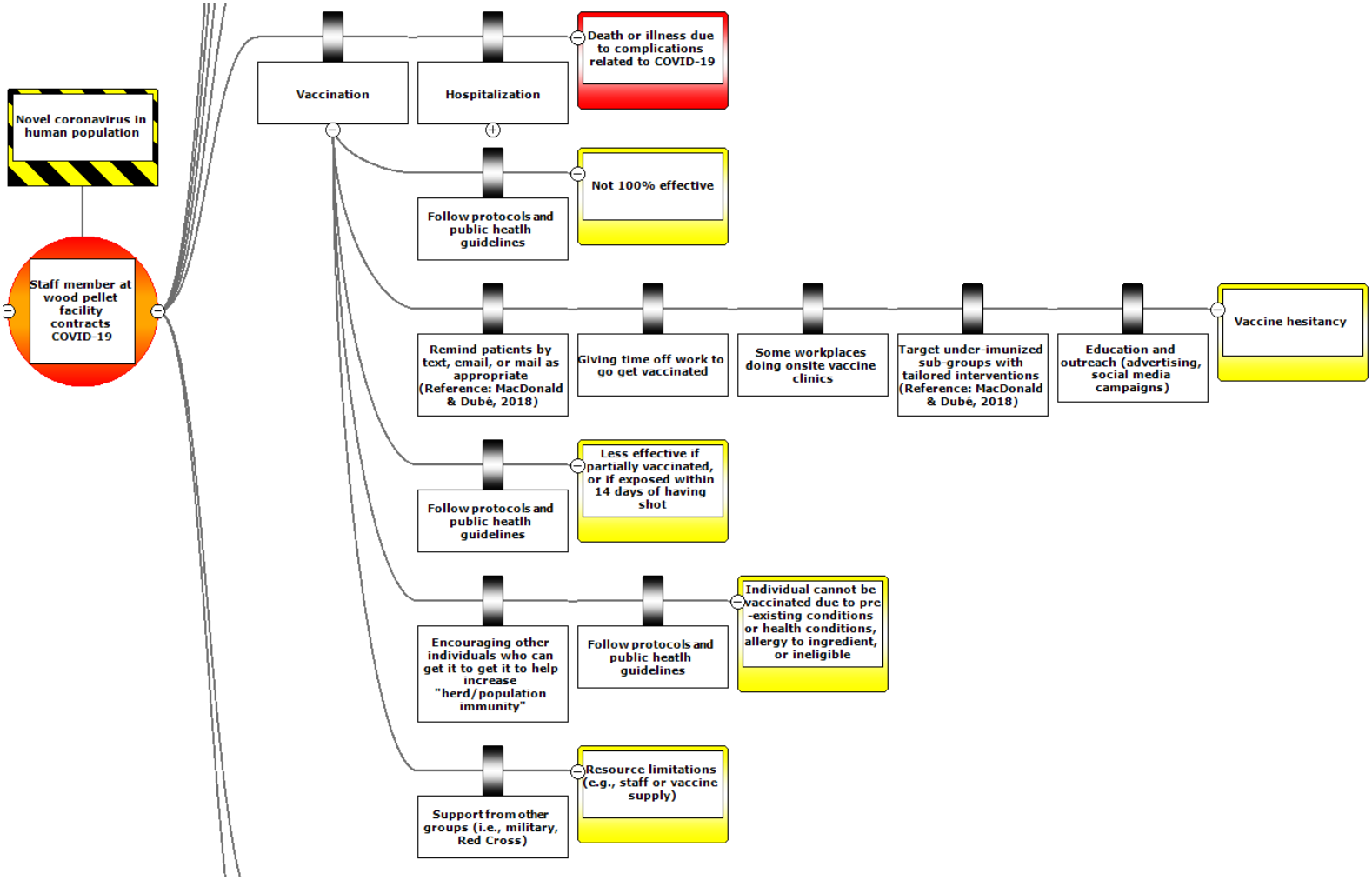

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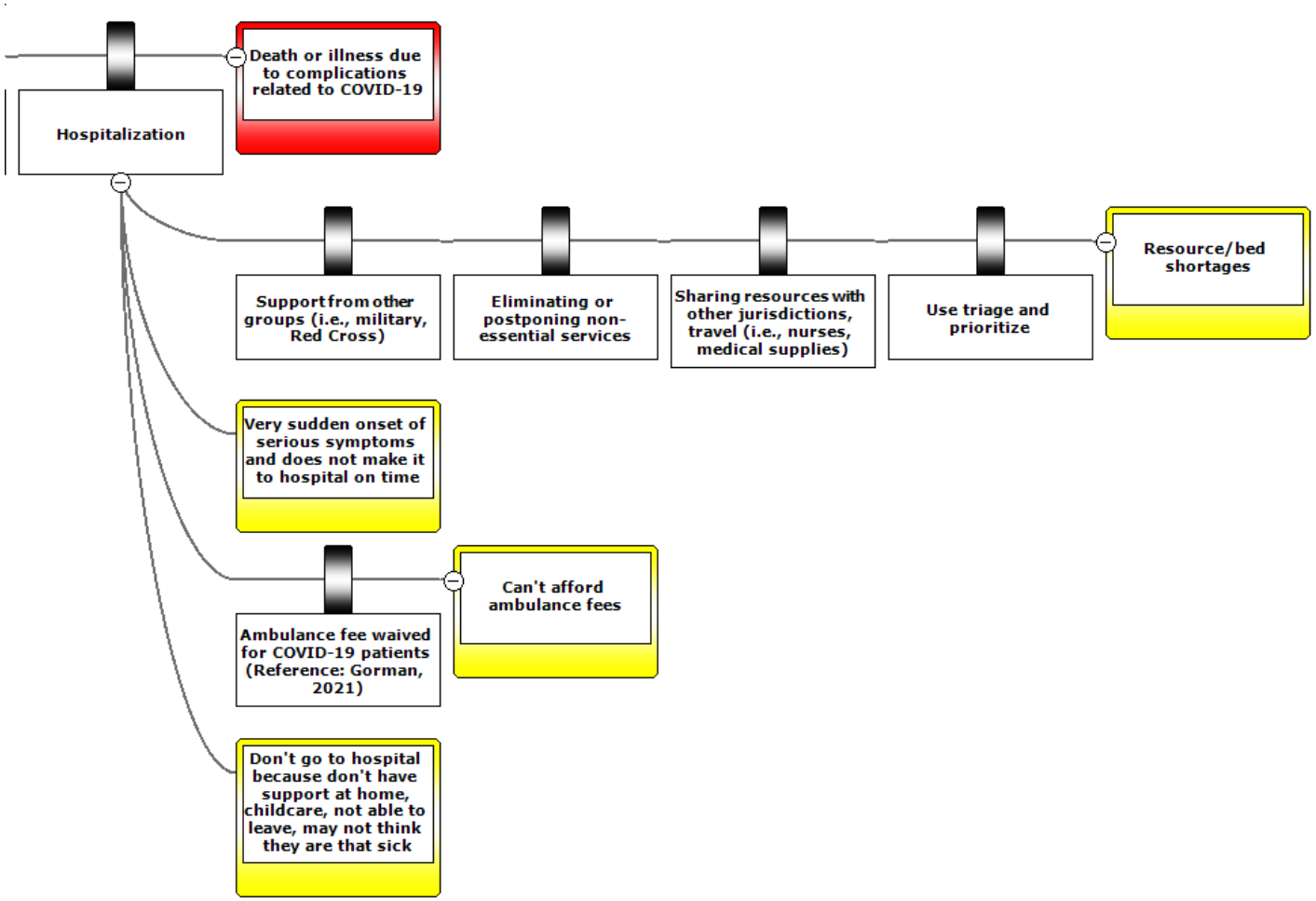

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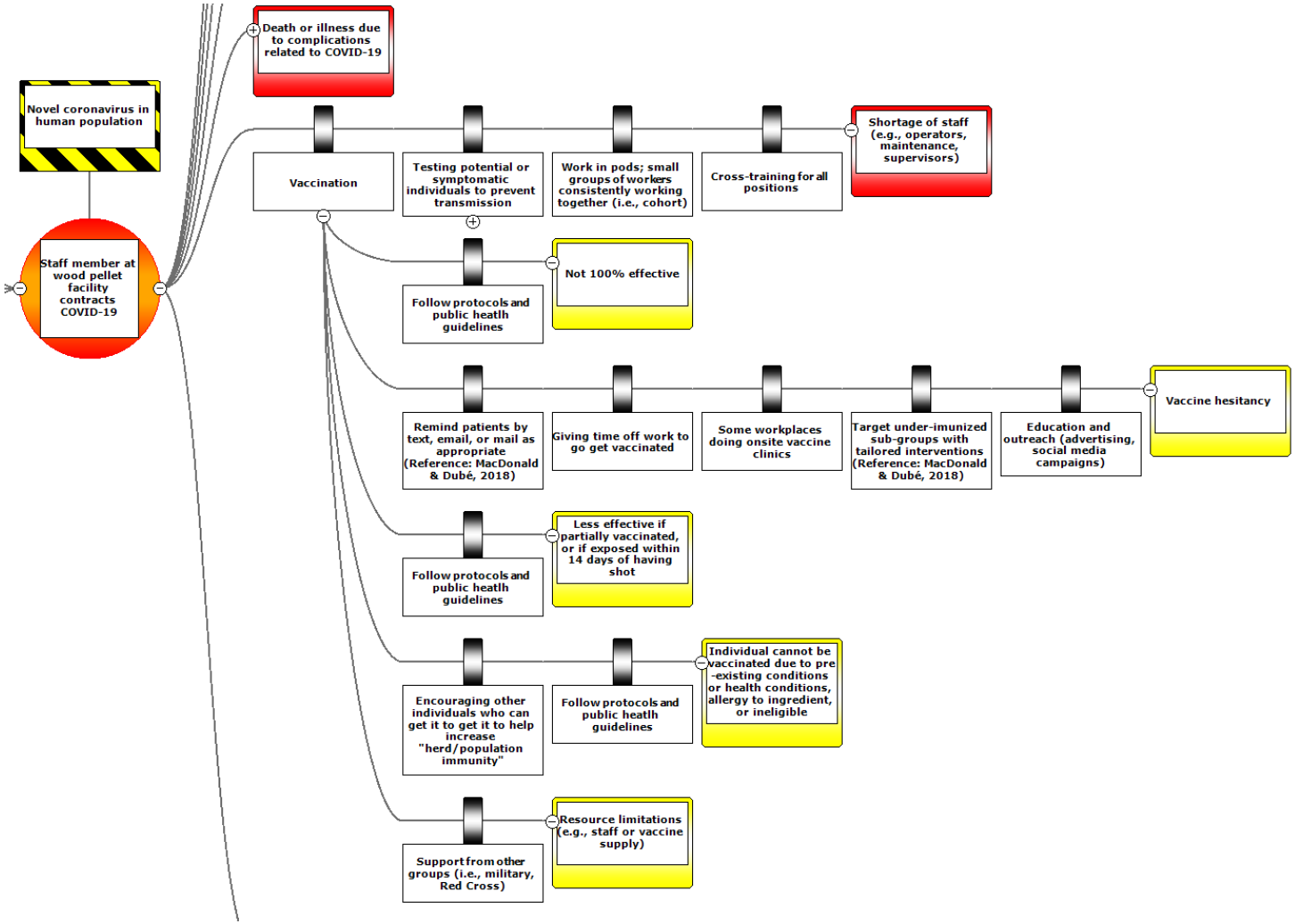

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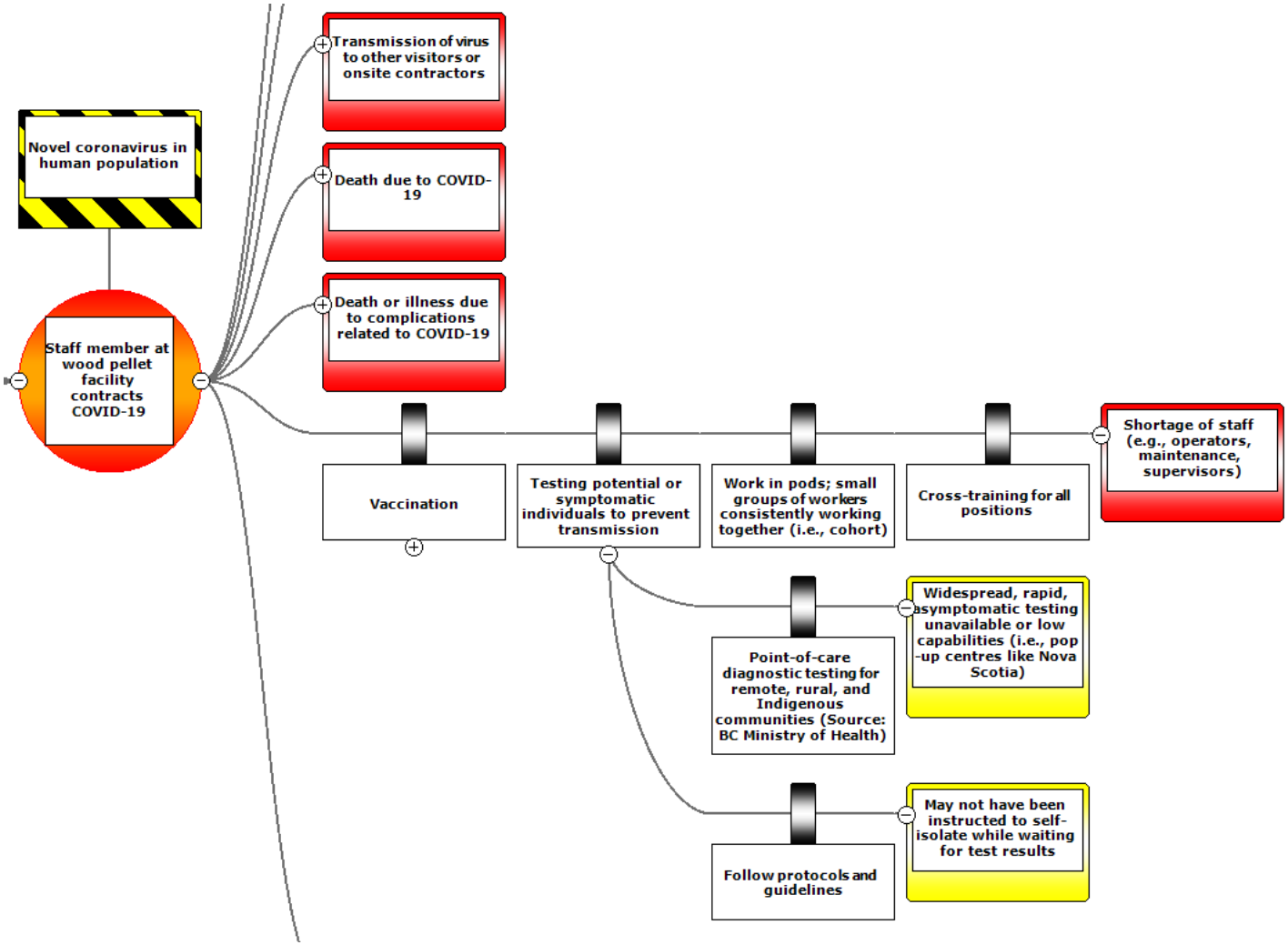

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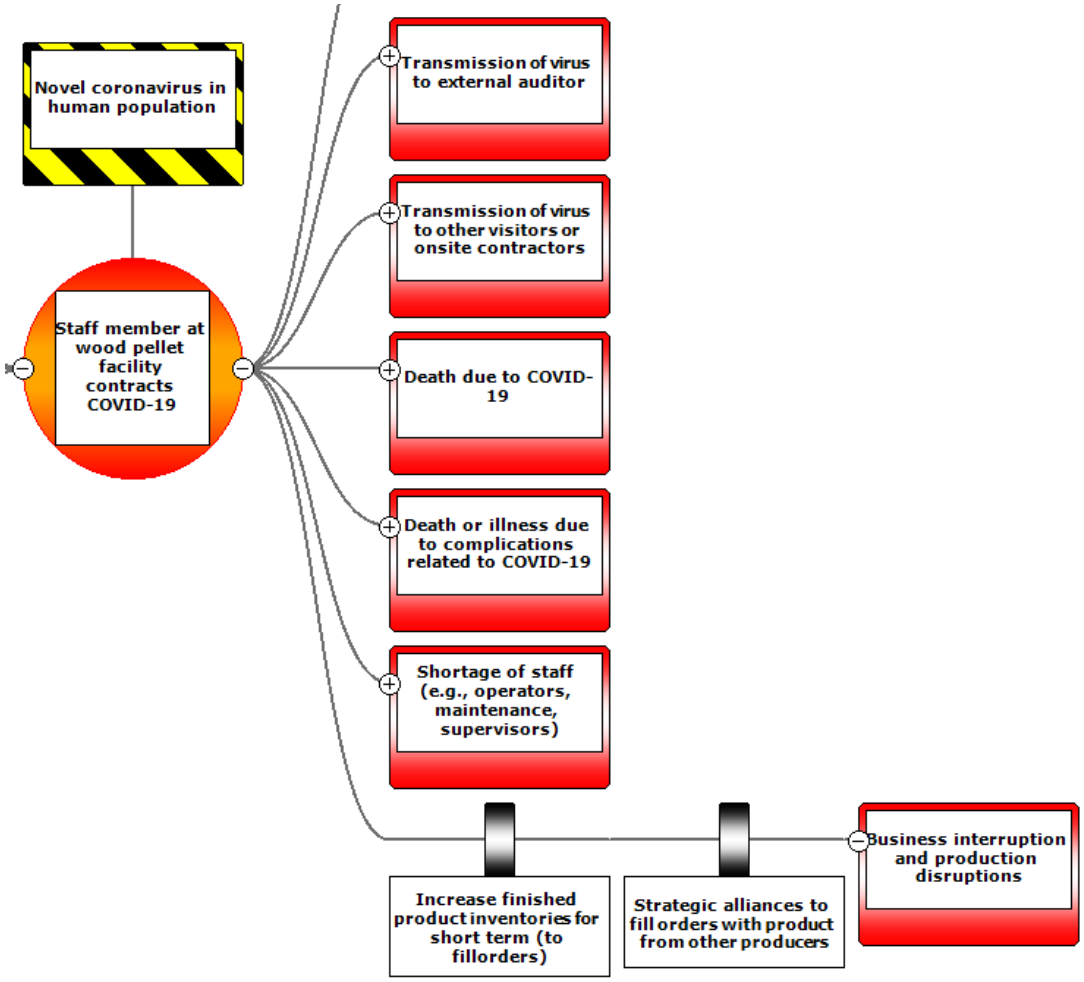


Figure B-48. BCFSC wood pellet facility COVID-19 bow tie diagram part 48

Appendix C Capture-Create-Channels Matrix

Note:

1. Enter your name in the far-left column
2. If any items are time-sensitive; enter that information

Usage Notes:

- KRB – Two areas of focus/two target audience
    - Leadership (Board and VPs)
    - Frontline team members

Table C-1. IWK IPAC bow tie communications ideas

Name	**Capture**	**Create**	**Channels**
	Developed bow tie diagram Fundamentals of bow tie analysis, and how it can be leveraged by IWK; what benefit does it have. Appreciation for the kinds of work, and all the things IPAC has done, through COVID-19 pandemic. Demonstrating successes. Looking to educate in order to recognize the successes of IPAC,	Presentation by Dr. Comeau - Introduction to BTA - Bow tie diagram developed - Demonstrate defense in depth (wide variety of barriers, not only relying on ADM controls, also engineered like negative pressure room) - Demonstration of results; no hospital acquired COVID-19	Presentation to leadership

	effectiveness of program, pride in successes and efforts. Identifying gaps for continuous improvement, justifying additional asks (i.e., CAPEX or OPEX) in the future. Understanding of critical barriers.	- Pandemic response unit; part of activities - Showcasing proper level of rigor	
	[Park for time-being]	Voice-over video	
	Basics of bow ties, COVID-19 barriers, for front-line workers	Communications and tools for frontline personnel. One-pager crew talk factsheet	
	Communication and education of COVID-19 barriers; justifying the reasoning behind decisions that are made. Demonstrating effectiveness of barriers, defense in depth, safety and effectiveness of barriers. Sufficiency of barriers. Encourage, demonstrate logical choice of barriers. Make people	Crew talk factsheet	

	feel safe so they can perform their job well. Demonstrate rigorous approaches. Improve stakeholder buy in for programs and procedures that are in place. Instill confidence in barriers through education.		
		Large prints (using Visio)	
		Bow tie graphics in Visio, with and without degradation factors and controls - Create different iterations of bow ties for different audiences and purposes	
	Hierarchy of controls		

Appendix D Communication Tool for IWK Executives/Leadership

Preventing the Spread of COVID-19 with Bow Ties

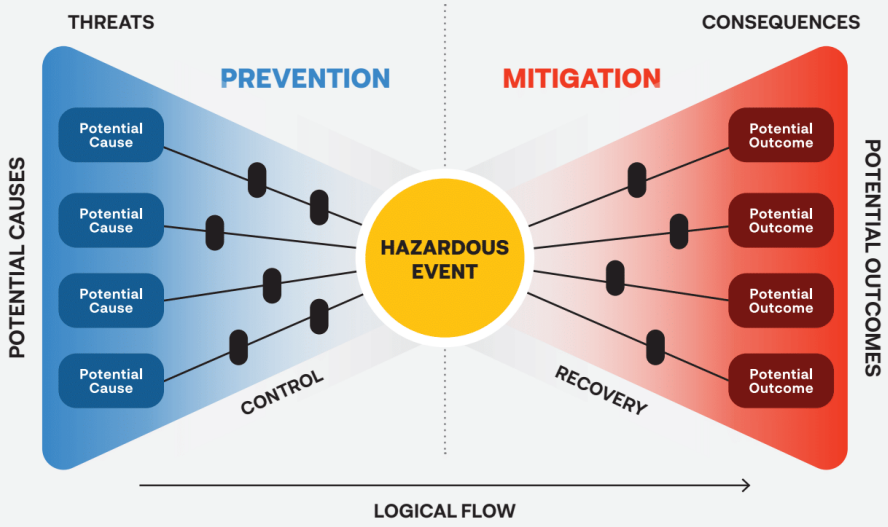
WHAT'S A BOW TIE?

A bow tie goes beyond just identifying the risk. It's a visual tool that shows how a hazard could lead to a dangerous event like an explosion or fire or viral outbreak at a given location. It allows us to assess how dangerous situations may arise and determine what controls we need to have in place in order to manage the risk.

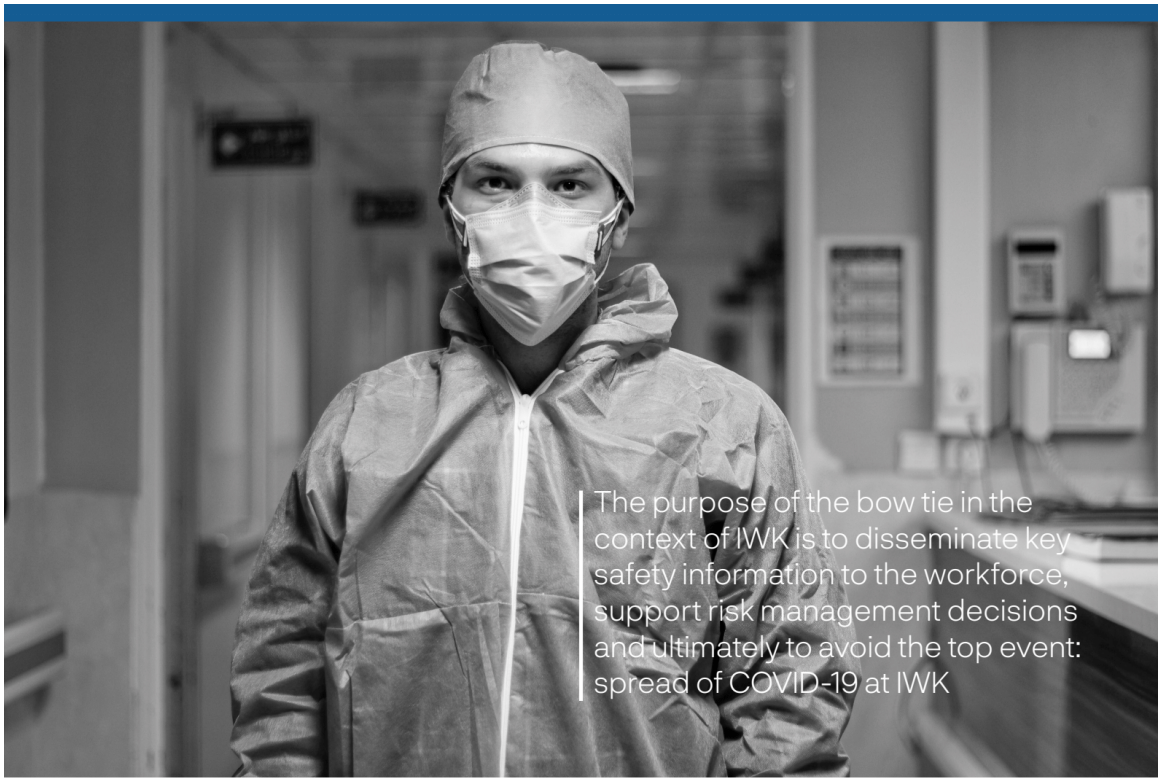
Bow ties are used across chemical, aviation, manufacturing, and other sectors around the world and are gaining in popularity in the health sector. The purpose of the bow tie in the context of IWK is to disseminate key safety information to the workforce, support risk management decisions and ultimately to avoid the top event: spread of COVID-19 at IWK.

A bow tie diagram consists of eight elements:

1. **The hazard:** a potentially harmful operation, activity or material
2. **The top event:** describes the loss of the control of the hazard
3. **Threats:** potential causes that can lead to the top event
4. **Consequences:** the unwanted outcomes of the top event
5/6. **Prevention and Mitigation Barriers:** measures that can prevent or mitigate the impacts of the top event
7. **Degradation factors:** conditions that reduce the effectiveness of the barriers
8. **Degradation factor controls:** help defeat the degradation factors



Can the POTENTIAL CAUSE create the EVENT and does that create the POTENTIAL OUTCOMES



KEEPING FRONTLINE WORKERS SAFE

Work on bow ties began at IWK Health Centre in 2021 and was inspired by a white paper Bow Ties in Risk Management published by the UK Energy Institute and the Center for Chemical Process Safety. Researchers in the Department of Process Engineering and Applied Science at Dalhousie University have also done extensive work in this field, much of which has been applied to chemical and manufacturing sectors across Canada.

The work was initiated through a partnership between Dalhousie University and Memorial University of Newfoundland and the Nova Scotia Health Authority to obtain a grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) to support research into how bowties could support hospital workers. They then reached out to the IWK team who were keen to explore the concept, which lead to workshops with the IWK team and development of the bow ties. A study published in 2016 in the International Journal of Health Care Quality Assurance, *Application of Bow-tie Methodology to Improve Patient Safety*, used bow ties to analyze risks threatening patient safety in ICU, looking at a 12-bed semi-closed medical ICU between 2011 and 2014. The study found that bow ties are a feasible tool for proactive risk management in an ICU.

Bow Ties:

- Allowed team members to generate practical solutions to address deficiencies;
- Promoted the clinicians' awareness regarding errors and conditions that might create undesired issues;
- Facilitated understanding of the required barriers for safer operations; and
- Highlighted that the bow ties can be time consuming and the reliability of the outputs depend on the reliability of the inputs.

BOW TIES AT IWK

Bow ties can be very complex given the multitude of risk scenarios and decisions that are made along every step that could lead to a top event.

The workshop participants identified six threats that could lead to the top event: spread of COVID-19 at IWK. The table below is a summary of one of the scenarios that was developed.

THREAT: Contract virus from asymptomatic patient

Barrier	Degradation Factor(s)	Degradation Factor Control(s)
Restricted communal areas (e.g., access to playrooms, closed kitchenette, laundry room)		
Pre-screening for planned visits; determine if patient has an exposure risk	Uable to contact/reach patient	• Call back; don't just try once • Layers of protection/multiple checks; checks at door and clinic
	Using out of date script, or ad libbing	Most up to date script kept online/on Intranet site
	Unaware that interpretation services are needed	Better flags in system
	Limited resources; time and staffing challenges (incl. staff turnover)	Volunteer recruitment
Door screening questions; determine if patient or visitor an exposure risk	Patients not honest about travel history or symptoms	—
	No door screening at night-time	—
	Tailgating/circumnavigating	Visual cues and signage
Physical distancing in public areas and when possible during assessments	Difficulty managing traffic	• Decreased number of people in health centre/building • Elevator limits • Communications with surrounding areas to encourage people to avoid area • Locked doors • Assessment of waiting area and limits put in place • Shut down food services during key times • Physical distancing markers • Posters, easily accessible and downloadable • Flow of traffic; separate entrances for childrens and womens patients
	Not followed	• Visual cues on floor and signage • Education

CONTINUED ON NEXT PAGE

THREAT: Contract virus from asymptomatic patient (continued)

Barrier	Degradation Factor(s)	Degradation Factor Control(s)
Limitations around day passes (exceptions only)		
Use of additional precautions based on risk assessment, including use of AIIR, as required (e.g., exposure history)	Door to AIIR propped open due to lack of understanding or work demands	Education
	AIIR PM not completed (e.g., pressures, filters, maintain higher levels of air exchanges)	—
	Incorrect risk assessment	• Education of the person performing the RA; online learning package, onboarding, orientation • Auditing
UPP worn by all direct care providers	PPE shortage	
	Worn improperly	Pandemic education on proper use of PPE
Medical grade face mask worn by patient in public areas and when possible during assessments	Proper procedure not followed	Education, training
	Worn improperly	Pandemic education on proper use of PPE
Practice good hand hygiene and sneeze/cough etiquette	Proper method not followed	Education, training
Routine cleaning and disinfection of high-touch surfaces and infection control practices (e.g. decontamination of equipment)	Proper procedure not followed	Education, training
Universal testing for all admissions and prior to all surgical procedures	False negative test results	—

NEXT STEPS

Not only will bow tie analysis help protect team members, patients, and visitors, it will provide additional assurance that the necessary steps and control measures are in place to ensure their safety. It may also help to alleviate staffing shortage in certain units where other team may be hesitant to assist. The bow ties will initially be communicated to the Infection Prevention and Control and Patient Safety teams.

Next steps will be to create strong, simple and effective visuals for teams, patients and visitors to communicate the steps being taken to prevent the spread of COVID-19 and keep everyone's loved ones safe.

FOR MORE INFORMATION

Name
Title
Email

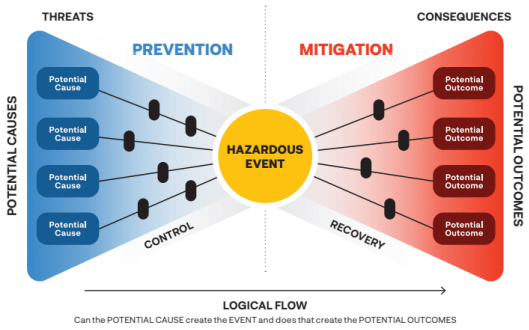
Appendix E Communication Tool for IWK Frontline Workers

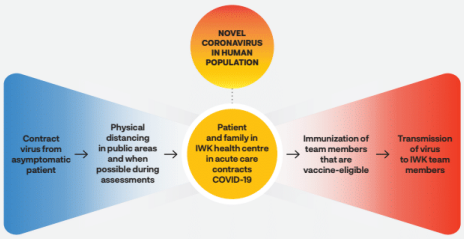
Preventing the Spread of COVID-19 with Bow Ties

WHAT'S A BOW TIE?

A bow tie goes beyond just identifying the risk. It's a visual tool that shows how a hazard could lead to a dangerous event like a viral outbreak at a given location. It allows us to assess how dangerous situations may arise and determine what controls we need to have in place to manage the risk.

Not only will bow tie analysis help protect team members, patients and visitors, it will provide additional assurance that the necessary steps and control measures are in place to ensure their safety.





PROMOTING A SAFE WORK ENVIRONMENT

Based on workshops with the IWK IPAC team, transmission of COVID-19 to IWK team members was identified as a potential consequence.

The IPAC team has implemented many barriers to protect IWK team members from contracting COVID-19 but there are steps we can all take. It is also important to understand that barriers can degrade, and control factors are needed to maintain their effectiveness.

Reducing the risk: a team effort

1. **Get vaccinated** against COVID-19 if you are vaccine eligible
2. **Maintain 2 m of physical distance** in public areas and when possible during assessments
3. **Use additional precautions** based on risk assessment (e.g., patient exposure history)
4. **Practice good hand hygiene**
5. **Have a buddy for PPE donning and doffing** to prevent self-contamination
6. **Perform contact tracing and testing** in partnership with Public Health and IWK Occupational Health, Safety, & Wellness (OHSW)
7. **Wear all required universal pandemic precautions** when providing direct care
8. **Consult with the IPAC team** if you have any questions