Trans Mountain Employs Extensive Risk Mitigation Measures for Trenchless Construction on their new Pipeline Expansion

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ABSTRACT

Trans Mountain Corporation started construction of their Trans Mountain pipeline expansion project at the beginning of 2020 which extends from the tank farm in Edmonton Alberta to Westridge Terminal on Burrard Inlet in Vancouver British Columbia. This is the culmination of at least 8 years of planning and design. This is likely the most challenging pipeline to be built in the last 20 years in North America. A key component on this project is the extensive use of Trenchless Construction including boring, technologies, horizontal directional drilling, direct pipe, micro-tunneling and tunneling. This project includes a significant number of major trenchless crossings in the designed alignment. As a result, the risk mitigation efforts around the major trenchless crossings utilizing these technologies has been paramount in the minds of the design and construction teams. This paper describes the trenchless construction methods that are employed and the risk mitigation efforts utilized around these major trenchless crossings.

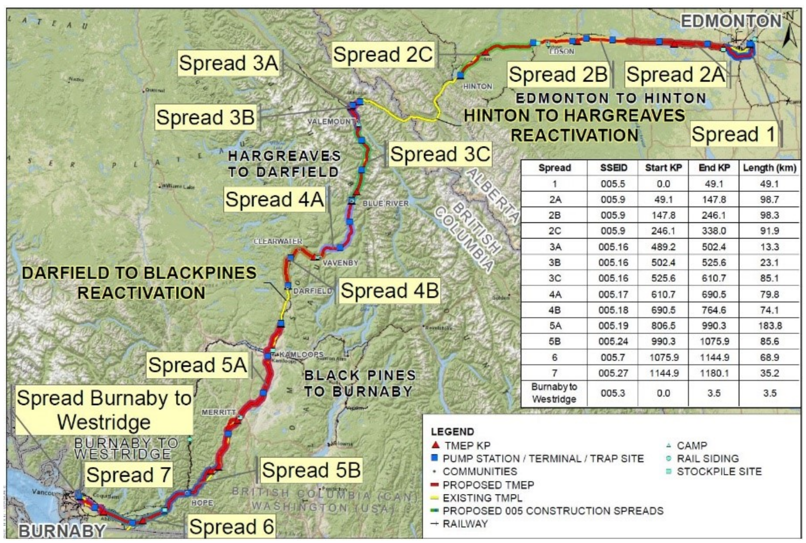
1.0 INTRODUCTION

Project risk is one of the major considerations on a mega project of the size of the Trans Mountain Expansion Project (TMEP). Managing that risk was of prime importance to the project team of Trans Mountain, UniversalPegasus International and BGC Geotechnical Engineering (BGC). Therefore, risk mitigation was always on the minds of the owners and the engineers. Risk was mitigated in numerous ways at various levels of the design and construction. It is well known that the primary construction risk on a pipeline project like this is the trenchless design and construction.

Kinder Morgan Canada (KMC) was the original project owner and was the company that conceived the original idea for the project. In 1953, KMC constructed the Trans Mountain Pipeline, a 1150 km NPS 24 pipeline from Edmonton Alberta to Westridge Terminal on Burrard Inlet in Burnaby, British Columbia as shown in Figure 1. Since that time, a need for additional pipeline capacity to transport the additional oil to market has been created. Other than the Trans Mountain Pipeline, all pipelines primarily take the oil to US markets. KMC conceived the idea of a new NPS 36 pipeline to the coast. This plan included utilizing, to the extent possible, the existing TMPL easements. The pipeline design started in 2012 with UniversalPegasus International (UPI) being awarded the engineering design of this Mega Project. This new pipeline is 980 km long and approximately 73 percent of the route is within the existing easement, 16 percent will follow other linear infrastructure and 11 percent will be new right of way.

Figure 1 Location of the pipeline alignment

Figure 2 shows the Alignment and the distribution of the route into 7 pipeline Spreads starting with Spread 1 in Edmonton and finishing with Spread 7 in the Lower Mainland.



Spread	SSEID	Start KP	End KP	Length (km)
1	005.5	0.0	49.1	49.1
2A	005.9	49.1	147.8	98.7
2B	005.9	147.8	246.1	98.3
2C	005.9	246.1	338.0	91.9
3A	005.16	489.2	502.4	13.3
3B	005.16	502.4	525.6	23.1
3C	005.16	525.6	610.7	85.1
4A	005.17	610.7	690.5	79.8
4B	005.18	690.5	764.6	74.1
5A	005.19	806.5	990.3	183.8
5B	005.24	990.3	1075.9	85.6
6	005.7	1075.9	1144.9	68.9
7	005.27	1144.9	1180.1	35.2
Burnaby to Westridge	005.3	0.0	3.5	3.5

Figure 2 pipeline Route from Edmonton Alberta to Burnaby BC

2.0 DETAILED ROUTING

Even though the route essentially followed the existing easement, early routing was essential to prove the alignment suitable for expansion. Trenchless crossings were targeted early as many of these existing crossings were not suitable for an NPS 36 trenchless crossing method. A number of these locations required minor to significant route changes. A good example is in Spread 7 at the very end of the project. The current NPS 24 route went through the streets of Burnaby. One key requirement was for two NPS 30 pipelines to go from the Burnaby tank farm to the Westridge Terminal. After looking at the various options including Horizontal Directional Drilling, a tunnel under Burnaby mountain was proposed by UniversalPegasus International (UPI). This eliminated the risk of placing 2 NPS 30 through the streets and allowed for the removal of the NPS 24 from the streets of Burnaby. The tunnel will now carry all the product directly from the Burnaby tank farm to the Westridge Terminal.

In addition to these challenges, regulations for constructing the pipelines have changed significantly since those early days. Now all named water crossings need to be constructed using a trenchless method if considered feasible. One of the first risk mitigations on the pipeline is the determination of geotechnical and construction feasibility of the crossings. The Canadian Energy Regulator (CER), formerly the National Energy Board (NEB), regulates all inter-provincial pipelines in Canada and requires the feasibility reports and knowing that not all trenchless construction is successful, require a contingency method to be named.

It was determined early on that trenchless construction was going to be a major component of the TMEP pipeline design. It was clear that there were going to be significant challenges in designing the pipeline route. Fortunately, trenchless technology has been developing over the years to fill the need. Trenchless methods have been developed along with analytical tools to mitigate the trenchless risks. The primary trenchless method utilized extensively in pipeline construction is HDD.

3.0 GEOTECHNICAL CHALLENGES

After the routing exercise, the first level of risk mitigation is carrying out a geotechnical investigation. BGC has worked closely with UPI to ensure that the proper number and depth of boreholes is utilized at specific crossings. UPI develops the basic early geometry of the crossing based on a number of factors such as the overall ground and the anticipated soil conditions. Early desktop studies are carried out in order to best anticipate the soil or bedrock conditions. With this a basic geometry is drawn up and then the borehole locations are plotted and the specific depth of the boreholes is determine. That way the most efficient investigative techniques can be utilized. For example the new technology of sonic drilling offers numerous advantages over the older traditional methods. This technology can sample in soil conditions that typical drilling technology might not be able to. Combining with the borehole program, where deemed necessary, parallel geophysics programs were carried out. Geophysics can provide additional information between the boreholes.

In addition to the geotechnical site investigations, geohazard work has been carried out throughout the alignment. Where possible, the route was realigned to pass these geohazard risks. However, at the Hardisty Creek crossing a significant geohazard was identified and it was determined that the best way to cross this zone was to do an HDD and design a profile that went below the geohazard. This crossing, although challenging was successfully crossed in 2020.

4.0 DETAILED DESIGN AND ANNULAR PRESSURE

Once the geotechnical/geophysics program is completed the preliminary design is updated to a final design and now takes into consideration the site specific subsurface soil/rock/groundwater conditions. Design for the most part follows the latest edition of the North American Society for Trenchless Technology's 'Good Practices Guidelines'. The Canadian Standard Association (CSA) Z662 is also followed where applicable to HDD technology. The Good Practices Guidelines closely follows the Pipeline Research Council International (PRCI) publications. All HDD crossings are designed with these publications in mind. As a result, all pipe in these major trenchless crossings are designed with heavy wall pipe and fusion bond epoxy (FBE) abrasion resistant overcoat (ARO)

As a further risk mitigation, three major trenchless crossings were designed with 'extra' heavy wall pipe. The reasons for this are concerns such as to allow for significant deepening of one crossing if the crossing had to be deepened was as a result of a fluid release at a shallower depth The Good Practices Guidelines also covers the additional design practice of annular pressure design curves at HDD crossings. The latest edition includes research carried out in the industry as well as industry experience to provide guidance on calculations for the annular pressure.

Contracting Strategy

A common practice in the pipeline industry is to have the mainline contract engage the trenchless contractors. This is a popular arrangement as then it is the mainlines contractor's responsibility to schedule the trenchless work and if the schedule does not work then it is the mainline contractor's responsibility to rectify the situation. However, when there are numerous trenchless crossings in a pipeline project, the trenchless construction will have a significant effect on the overall pipeline schedule. For the majority of the project the major trenchless construction was disconnected from the mainline contract. This allowed Trans Mountain to have control of the trenchless contractors. It is felt that this had a significant impact on the risk as it gave the project direct control of the trenchless contractors, their equipment and the schedule.

Noise Levels

Another risk relative to shut down during construction of the trenchless crossings is the level of noise at the HDD rig sites. This falls under one of the 156 conditions that are set by the Canadian Energy Regulator (CER) that need to be met. This is Condition 74 Noise Management Plans. HDD drill rigs are stationary and tend to be on site for a number of months. Considering this, TMEP engaged a specialist consultant to prepare noise management plans for all the HDD sites as well as the Direct Pipe sites. A sound mitigation plan is developed for each site which includes temporary sound absorbing walls around the sites.

Other aspects of the drilling process which adds significant risk are things such as fluid release, particularly into water bodies such as the North Saskatchewan River in Edmonton, and the amount of drilling fluid waste that is generated at every site. No HDD is even started without both of these issues fully resolved with a detailed plan in place.

5.0 TRANS MOUNTAIN RISK MANAGEMENT PROGRAM FOR CONSTRUCTION

The Trans Mountain Project instigated a Project Risk Management Program (PRMg) in 2016 and has developed full working processes to conduct both qualitative assessment and quantitative risk analysis on uncertain and risky activities, such as major trenchless crossings. The PRMg clearly defines the framework, requirements and implementation of Trans Mountain Expansion Project (TMEP) risk management program for both internal and external applications. It is intended to identify critical project risks, raise red flags to alert the Senior Leadership Management Team (SLMT) at the earliest opportunities and plan for response actions (e.g. mitigation or avoidance).

On August 31, 2018 when TMEP became part of Trans Mountain Corporation (TMC), a wholly owned subsidiary of the Canada Development Investment Corporation (CDEV) that is accountable to the Parliament of Canada, an Enterprise Risk Management (ERM) policy from CDEV was also issued to TMEP with an intention to strengthen the risk management practice. Furthermore, the risk assessment and analysis are part of NEB's 157 conditions in 2016 and CER's further 156 conditions in June 18, 2019. Accordingly, Trans Mountain risk management team developed a Risk Management Work Process (Figure 3) in the PRMg to guide risk identification, ranking and risk response planning during project execution.

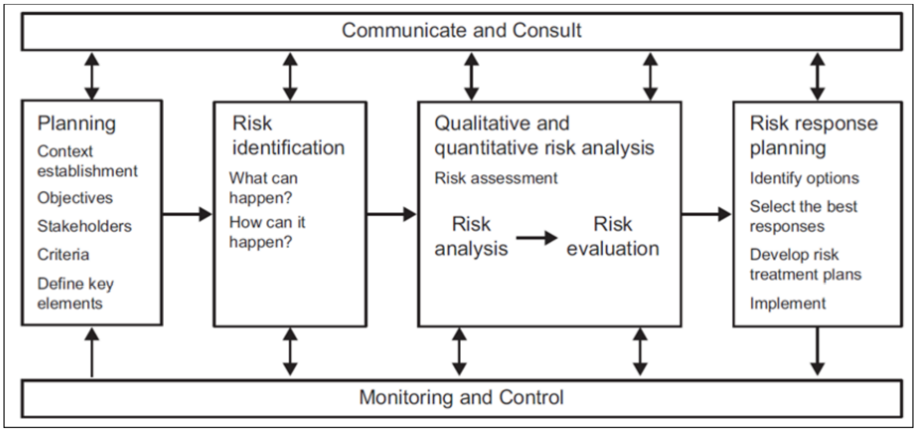


Figure 3: Project Risk Management Process

The construction execution plan (CEP) that both contractors developed, and internal disciplinary teams prepared, are the basis for field mobilization of major equipment fleet and personnel. Transmountain has mandated an independent External Construction Readiness Review (ECRR) and semi-quantitative risk analysis process for any major trenchless crossings. The process evaluates readiness of early regulatory permits, environmental compliances, execution plan, contractual obligations and supporting functions while the risk workshop identifies and assesses critical risks that may jeopardize the execution, then allowing the management team ample time to prepare risk mitigation plan and control measures.

6.0 HDD RISK EVALUATION METHODOLOGY & WORK PROCESS

The Trans Mountain Project had initially designed and planned for over 40 Horizontal Directional Drilling (HDD) and Direct Pipe (DP) for the entire project, then streamlined and optimized down to 37 for regulator's approval in 2018. Out of the 37 HDDs / DPIs, UPI identified 9 critical and challenging drills that a higher than normal risk to fail because of their complexity, geotechnical conditions and subsurface formation. The identification of these 9 critical HDDs / DPs was largely based on the SME's heuristics and their rich project experiences of many similar crossings. To a certain degree the assessment process of critical drills heavily relied on engineering and the design team's subjective judgements, with very little input from HDD drilling contractors, because at that time Trans Mountain had not secured any HDD contractors yet.

The first 11 HDDs were planned to be drilled in early 2020 by the HDD contractors subcontracted through the Main General Construction Contractor (GCC) for the pipeline segment within the Transportation Utility Corridor (TUC) in Edmonton. In late 2019 Trans Mountain management team asked the contractors for their confidence level for successfully completing the HDD drills and pull-back operations. They were also asked about the contingency plan if one of the drills fails. Based on the responses from the execution contractors and considering the nature of cost reimbursable contract model with the GCC, Trans Mountain decided to mandate a thorough and robust readiness and risk evaluation process for each HDD operation. As a result, the following were established to assist the evaluation process:

- 70-item HDD Construction Readiness Review Checklist (CRR)
- HDD Failure Criteria and Decision Tree with Failure Branches
- HDD-specific Risk Evaluation Matrix (Boston Box, or Heat Map)
- Construction Risk Register with Mitigation & Residual Risk Level

Prior to holding HDD risk workshop, owner supporting team members, design engineers and construction contractors will have to participate in a Readiness Review session for each planned and approved HDD operation. The rigorous CRR process confirms answers to 70 questions from responsible stakeholders in the following six (6) key categories:

- Contractual Assessment
- Permits, Accesses and HDD Site Preparation
- Constructability Reviews
- Execution Strategy
- Safety Requirements
- Drilling Waste Management

Upon the completion of CRR sessions, risk workshops follow attended by key HDD stakeholders and facilitated by an independent risk specialist who prompts SMEs with questions, provides guidance, enforces process and streamlines risk rankings using the Risk Evaluation Matrix (Figure 4). Accordingly, risks are either accepted with contingency plan or mitigated with action plans & control measures. Residual risk levels will be evaluated for each mitigated risk items for final acceptance.

At the beginning of each HDD risk workshop, the design engineer would explain to all attendees and emphasize the "risky areas" in the geotechnical information, borehole logs, design profiles, and rig configuration. The execution contractors would also present their execution plans, highlight their "high risk tasks" and table their existing solutions, such as mud controls or adding an exit side rig.

The risk identification workshop would typically deploy a brainstorming method with the SMEs and combine it with the Delphi technique to streamline the final outputs, however different workshops styles must be used during the Covid-19 pandemic period as all risk workshops are being held virtually. A set of prompt questions and past HDD project risk items are used for workshop SME / attendees to identify new risks, verify and validate registered risks, trigger conversations and develop new "scenarios and assumptions". Once risks are properly identified and screened, each of risk's severity level is ranked using the Risk Matrix in Figure 4 based on the vulnerability, probability and consequence. High severity level risks would then be further studied to establish appropriate risk response plans for mitigation.

Risk is a function of the values of threat, consequence, and vulnerability; its severity is ranked based on a risk's likelihood to occur, degree of impact (to project's objectives), and how vulnerable TMEP is exposed to a risk's occurrence with existing controls in place. The 5 x 5 risk ranking Boston Matrix follows the tenets outlined in Trans Mountain company's Enterprise Risk management (ERM). Risk can be scored with the following equation:

Risk Severity Level (5 – 40) **=**

Probability (1 – 5) **x** Consequences Max (1 – 5) **+** Vulnerability (5, 10, 15)

Typically, the TMEP project team would accept risks with severity scores lower than 19 and put them under "monitoring"; for risks with scores higher than 25, effective risk mitigation plans and control measures are expected to be developed, implemented, results validated and residual risk levels ranked.

Probability		NEGATIVE PROJECT RISK MATRIX - TMEP				
Possible >90%	5					40
Likely	4				31	
Probable (50%)	3			24		
Unlikely	2		19			
Seldom <10%	1	16				
Vulnerability (how vulnerable?)	Consequence (a single risk occurs)	1	2	3	4	5
		Minor	Moderate	Major	Critical	Extreme
Low (5)	Financial Impact	<$5,000	$ 5,000 to $ 10,000	$ 10,000 to $ 500,000	$ 500,000 to $ 1,000,000	> $ 1,000,000
Medium (10)	Schedule Impact	1.25 x Planned Schedule	1.5 x Planned Schedule	2.0 x Planned Schedule	2.5 x Planned Schedule	3.0 x Planned Schedule
High (15)	Health & Safety Environmental Regulatory	- Medical aids - <1 year reclamation - Corrective actions	- No restricted duty - No irreversible - Small fines	- Lost time injuries - Limited reversible - Notice of violations	- Single fatality - Limited irreversible - Very large fines	- Multiple fatalities - Major irreversible - More legal actions

Figure 4: Risk Evaluation Matrix (Boston Box)

7.0 RISK REGISTER AND RISK RESPONSE PLAN

An important part of risk management process is to properly document identified risks for ranking, response action planning, and contingency development. Trans Mountain has two risk register systems that are concurrently used for risk identification, ranking, response planning and residual risk level recording.

Risk registers are depositories used to capture and store risk information (from risk event to ultimate outcome) in an accessible and understandable format. They are controlled project documents that should be reviewed and updated regularly for risk status and response action tracking; it is dynamic in nature and stays live following project's progress. The input to the risk register is "workshops, reviews and updates" and the output is project risk profile with associated actions. The two systems are:

- TMEP Risk Registers in Excel spreadsheet format for easy identification.
- PIMS Risk Module database for records keeping reporting & optimization.

The Risk Register contains RBS (Risk Breakdown Structure) that lists the categories, sub-projects, stakeholders, functions, responses, and statuses that assist in classifying the risk. In a typical risk register the RBS identifies risk ID, categories, location, disciplinary function and date the risk is identified. For example, a risk assessment was performed for the 1,007 meters long Hardisty Creek HDD, designed to be executed using one single 1.1 million LBF drilling rig. At the virtual HDD risk workshop of May 28, 2020, the risk was unanimously identified and described as:

Identification:
"Drill hits the conglomerate zone leading to possibility of losses (if uncemented), drill string control, downhole equipment loss, and worst case of collapse (without use of secondary drill rig)".

Ranking:
The risk severity was ranked as **25** based on the Probability 3 (50%) x Consequence 5 (>$1M) + Vulnerability 10 (medium). This was not a tolerable risk, so the UPI design team, Direct Horizontal

Drilling and Trans Mountain disciplinary SMEs at the workshop discussed,and finally concluded that a risk mitigation was needed and was to be developed as:

Response Plan - Mitigation:
"Use of second rig (440 LBF) at the exit side; use of surface casing at both entry and exit. Grouting Plan is to be developed in case it is needed".

Residual Risk Level:
The above risk mitigation plan was then presented to Senior Management through Management of Change (MoC) process for approval. Once approved with additional funds, the second rig of 440 LBF was deployed and placed on the exit side whilst 2x80-meter-long Dia. 60" surface casing at both entry and exit were brought to sites for installation.

The residual risk severity level was ranked again at 14 based on the Probability 2 (30%) x Consequence 2 (<$10K) + Vulnerability 5 (low). This was an acceptable and tolerable risk, but the HDD team was also requested to develop a "downhole grouting program which may be used if necessary, to create a stable conglomerate zone". Two months after the risk workshop and implementation of risk mitigation plan, the Hardisty Creek HDD was successfully completed to the satisfaction of key stakeholders.

The other example was the risk evaluation in February 2020 of the 738-meter-long Whitemud Creek HDD, which was identified for a "potential loss of drilling fluid due to historical mining in the area, and the failure of the planned grouting program". The risk severity was ranked 20 with the mitigation plan of "accelerate geophysics and geotechnical program to be completed by end of March 2020". However, the implementation of the mitigation plan and grouting program would have taken a lot longer, hence the project team made a schedule adjustment, and postponed Whitemud Creek HDD from July 2020 to October 2020, which was another success story.
The residual risk level however is the final thermometer to validate if an identified risk can be closed or left open for monitoring or requiring further action. However, ALARP (as low as reasonably practical) principle must be always followed.

8.0 T.E.A.M. AND RESIDUAL RISK LEVELS

Identification and ranking of HDD operational risks are only a part of overall risk management process, how to effectively lower high-risk items to tolerable levels through effective risk response plan is a challenge not only for Trans Mountain but the whole construction industry. Depending upon the assessed risk level, a corresponding risk response action plan needs to be developed by the proposed risk action owner, who is the authorized individual with allocated resources, for each "high" risk item. The risk action owner is the most capable person or specialist company who is equipped with necessary know-how, expertise, and resources to ensure the response action plan is most effective and can be efficiently implemented and will achieve the intended result. Risk responses can be one or more of the following four strategies (T.E.A.M. Figure 5):

1. **T**ransference (Allocation): To third party by changing contract strategy; or buy insurance;
2. **E**limination (avoidance): Changing execution strategy to avoid risks; or explore alternatives;
3. **A**cceptance (Contingency): Understanding the characteristic of risks with contingency plan;
4. **M**itigation (actions): Make appropriate plan to contain the risk exposure or reduce probability;

In early stage of HDD design, “Elimination” is the most effective way to avoid risky design or execution because we have options; “Transference” performs the best during contract formation and negotiation phase because we can “pass” risks to the other capable parties; “Acceptance” is often a strategy for low severity risks during execution phase whilst the “Mitigation” if often deployed to reduce overall risk severity level. However, each risk response plan will likely bear the consequence of additional cost or time, in order to lower those risks to tolerable levels; or company may also choose to carry contingency amount by accepting some risks.

The Trans Mountain Project risk management team worked in early 2019 with UPI design team to not only have identified several critical risky HDD operations, but also subjectively quantified the potential cost impacts of “various failure scenarios” and associated probabilities of failures. As a part of Class 2 cost estimating process, a Monte Carlo analysis technique (by discrete Poisson Distribution) using Riscor Model was deployed to scientifically derive an appropriate contingency amount. In this case, Trans Mountain project contingency has considered and included the following with 50% probability and a consequence of $25 Million.

“One or Two of 37 Major Trenchless Crossings (HDD) planned for the project may fail completely resulting in complete re-drill. All crossings are on the critical path. Due to the quantity, number, locations and lengths of the crossings there is a significant increase to the risk on the project”.
Early geotechnical investigation and borehole program played an important role in HDD design and was the first level of risk mitigation. The geotechnical engineering consultant, BGC, has worked closely with UPI to ensure that the proper number of boreholes is utilized at a specific crossing with the location and depth of the boreholes jointly prepared and analyzed. This allowed better understanding of subsurface formation, seismic and basic early geometry of the crossing, so that HDD design profile could eliminate or avoid such uncertain and risky factors. Raft River HDD, for example, faced challenges of high ground water table, high elevation change, buoyance control, sandy soils and drilling this problem became a major issue. In this case, the geotechnical consultant conducted an additional field investigation, analyzed more historical data and assisted with a revised design profile with different entry locations and angles.

However, risk management is a value-added process, ensuring that the mitigation costs and the incremental gains (benefits) are in proportion hence the use of the ALARP principle. All identified risks shall be initially ranked, effective risk response plans developed with costs and time, and efficiencies of such plans measured. Trans Mountain has strived to mitigate initial risk level to “As Low As Reasonably Practical” (ALARP) using “best available and most efficient means.” ALARP principle, depicted in Figure 6, ensures that the residual risks are reduced as far as reasonably practicable, at which point these risks would be finally accepted with “simulated” contingency in place.

9.0 CONCLUSION

Trans Mountain and UPI have worked on the pipeline engineering and design, including some of the most challenging HDDs and DPs in the industry, since 2015 with a goal of minimizing, not entirely eliminating, potential HDD project failures.

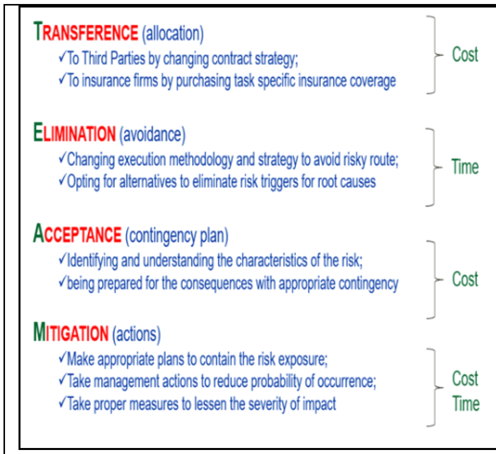


Figure 5: TEAM Approach

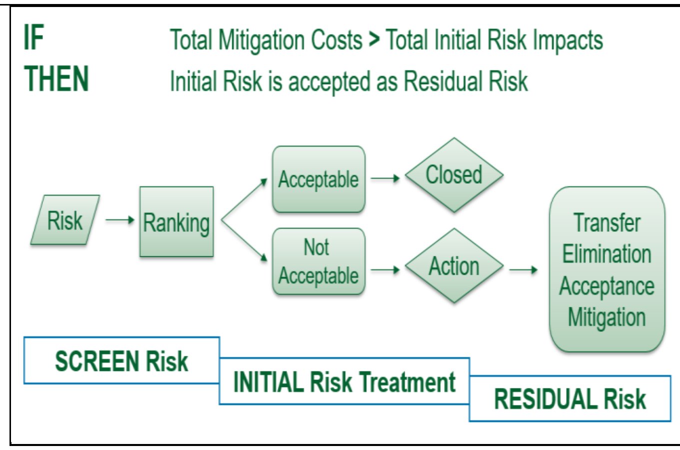


Figure 6: Residual Risk and ALARP Principle

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Trans Mountain and UPI have worked on the pipeline engineering and design, including some of the most challenging HDDs and DPs in the industry, since 2015 with a goal of minimizing, not entirely eliminating, potential HDD project failures. Changes are inevitable but failures should be preventable if plans and processes are strictly followed, readiness reviews properly conducted, and risk evaluations are rigorously conducted.

Based on the successful completion of first 14 (out of 37) HDDs and one re-drill in 2020, it is evident that risk management and evaluation of each HDD prior to field mobilization added values to the execution team, increased the probabilities of success and allowed time to improve execution plans by incorporating necessary changes. Through the risk process, the following have been either reviewed for better planning or decision-making:

- The use of a trenchless crossing method instead of open cuts to avoid public issues or environmental sensitive wetlands
- Identifying early on the geohazard area by taking geology/geotechnics/land issues into consideration
- The use of extra heavy wall pipe to mitigate steering issues and other failure potentials.
- Noise level mitigation by designing and use of effective sound barriers around HDD operations;
- The use of drones to monitor for fluid release for impassable HDDs

At the time of writing this paper, the number of HDD, DPI and Micro-tunnels has increased by more than double the original 37 HDDs to 82 major trenchless crossings. More than ever, the risk mitigation efforts around these major trenchless crossings utilizing new technologies, better processes and risk simulation techniques have been paramount in the minds of the design and construction teams.

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