RISK AND VALUE ANALYSIS
METHODOLGY USED FOR THE REFURBISHEMENT OF AN URBAN ROAD TUNNEL

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Outline of the presentation

1. Introduction and Project Objectives
   - Tunnel description, constraints, and safety (fire, evacuation, etc.)
   - Previous work and feasibility project for emergency management
2. Integrated approach for tunnel safety upgrade
   - Hazard Analysis versus Risk Analysis and performance criteria
   - Identifying the Tree of Safety Functional Needs
   - Evaluate Worst Case Scenario on existing tunnel
   - Generate alternative design and optimizing the best solution
   - Value Analysis for choosing the optimal set of solutions
3. Conclusion and lessons learned

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Ministère des transports du Québec

Transport Québec Mission

Ensure the mobility of people and goods throughout Quebec on safe and efficient transportation systems that contribute to the sustainable development of Quebec.

Operated and Owned Infrastructures

- 3,934 bridges and 5 tunnels (2 major in Montreal)
- 29,600 km of roads (2-lane equivalent length)
- 92 ports and piers and 23 airports (Nordic)
- 6,574 km of cycling routes (Route Verte)

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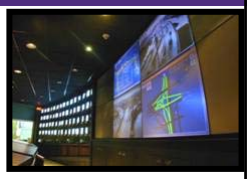

Transport Quebec - Montreal Department

Responsible for the maintenance of

300 (~) road structures (total of more than 800,000 m²)
200 (~) other infrastructures (walls, pumping stations, etc.)
140 km of road highways varying from 4 to 8 traffic lanes
1,000 (~) overhead traffic signs (¼ of the provincial inventory)

Responsible for the management and operation of

A very busy urban road network with more than 200,000 veh./day
A Traffic and Telecommunication centre operating 24 hours / 7 days / week
An Operation Control Centre for the Montreal Urban Area Tunnels
The longest and busiest urban tunnel in Canada (130,000 veh./day)

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Tunnel description and safety equipments

- 1.8 km underwater urban tunnel - frequently congested
  - 2 unidirectional 3-lane tubes under the St. Laurent River
  - 1 central gallery for services, emergencies and evacuation
  - 2 identical and symmetrical ventilation towers on each side
- 40-year old tunnel constructed between 1963 and 1967
  - the 2 end sections and towers were constructed on-site
  - a central section made up of 7 prefabricated elements built in a dry-dock, floated off, towed over a trench dug in the riverbed, and sunk into place using 1,500 tons of ballast
- Part of Trans-Canada Highway with over 130,000 veh/day
- Control Centre 24/7 with many surveillance cameras
- No transport of dangerous goods allowed

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Tunnel description and safety equipments

- Ventilation (semi-transverse in supply – 3,200,000 cfm)
  - Fresh air drawn in by 8 supply fans and forced into the central gallery, from which it is distributed to the traffic tubes
  - Polluted air expelled at both ends of the traffic tubes and through 8 exhaust fans located on the top of the traffic tubes
- Other electromechanical equipment and controls
  - 3 pumping stations in the middle and in both sides of tunnel
  - 4 emergency power generators (4 x 400 KW)
- Fire protection and other fire safety equipment
  - Walls of the traffic tubes are covered with ceramic tiles
  - Heated wet standpipe systems with fire and jockey pumps
  - Portable fire extinguishers available in 48 wall cabinets

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Tunnel description and safety equipments

- Means of egress located every 60 m
  - central gallery connected by 48 exits doors
  - cross-passages available between traffic tubes
- Regular and emergency lighting
  - High-pressure sodium lighting systems
  - Photocells for day and night adjustments
- Traffic and emergency signs in the tunnel and at the portal
  - variable message signs and other LED-enabled signs
  - kilometre markers and illuminated exit signs
  - fire cabinet signs showing fire protection system available
- Communication equipment
  - SOS telephone and antennas for all cell phone providers

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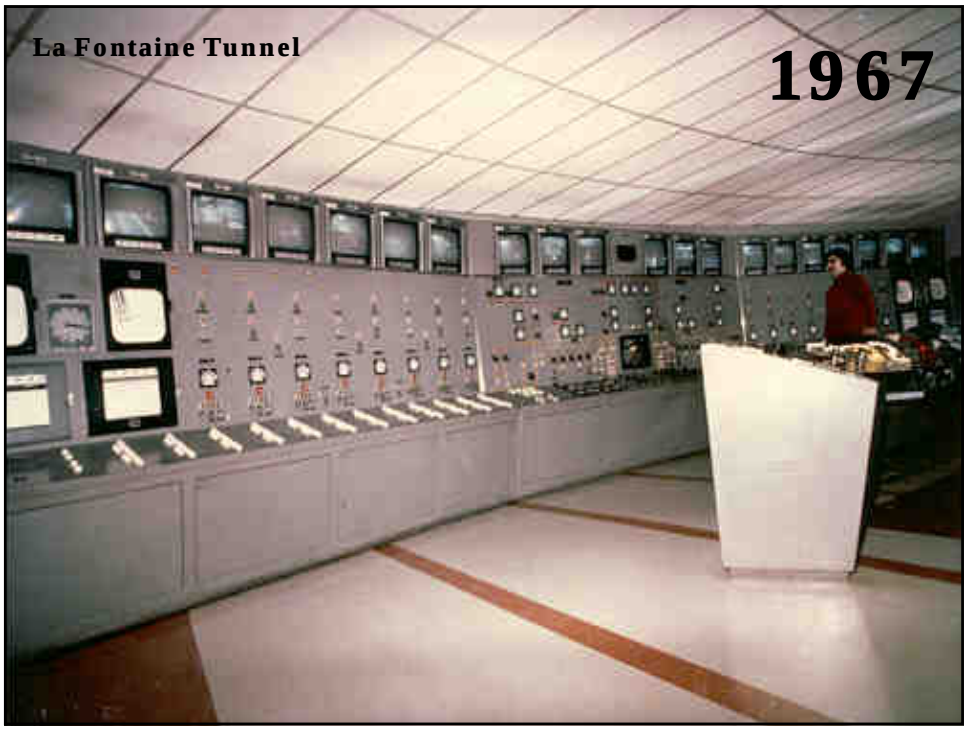
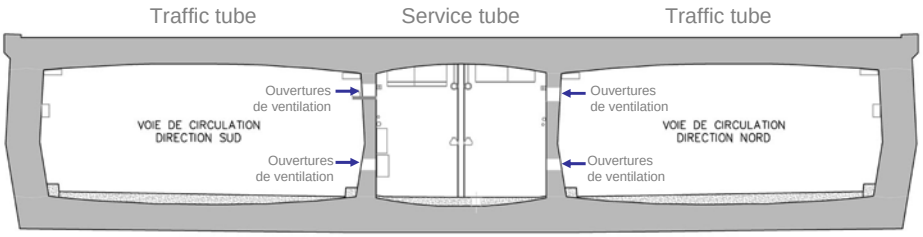
La Fontaine Tunnel
1967


La Fontaine Tunnel
2009


La Fontaine Tunnel
1967


La Fontaine Tunnel
2008

La Fontaine Tunnel



Cross-section

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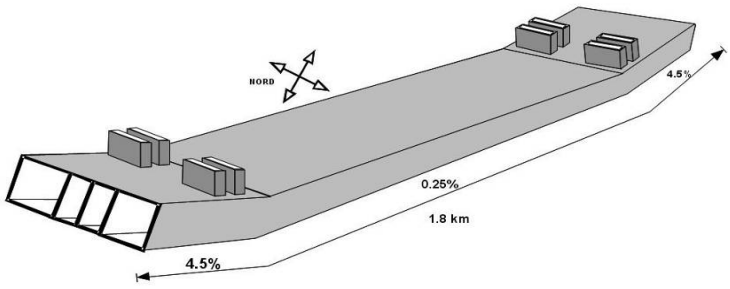
La Fontaine Tunnel

- VENTILATION: Semi-transverse ventilation with reversible fans in supply and extraction at the ends.
- EMERGENCY EGRESS: Central corridors used for air supply ventilation, drainage and as a refuge or for evacuation.



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La Fontaine Tunnel

- Existing functions of the service tube:

Multiple usage

- Intake or exhaust ventilation
- Sheltering and people evacuation
- Access for maintenance teams
  - drainage gutters, pumping stations,
  - electrical cables, telecommunications cables, and
  - other instrumentation equipment are located in this tube.

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La Fontaine Tunnel

- Service tube may be filled with smoke
- Service tube may be used as exhaust duct



La Fontaine Tunnel

- Air currents of 50 km/h in certain scenarios

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La Fontaine Tunnel

- Presence of drainage gutters that connect to the heated drainage systems for water infiltration control.

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Previous feasibility and redesign work
for smoke ventilation and people evacuation

Objective of previous studies

- Upgrade users' safety in case of fire un the tunnel;
- Feasibility of the central tube redesign for people evacuation;
- Present recommendations on possible feasible solutions;

Scope and content

- Performance criteria based on prescriptive approach (NFPA, PIARC);
- Numerical modeling of smoke control and people evacuation;
- Numerical modeling of users' behaviour in case of a fire in the tunnel;
- Identification and feasibility assessment of 9 solutions;

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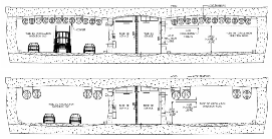
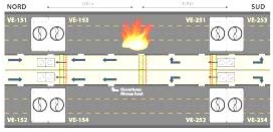
Previous feasibility and redesign work
for smoke ventilation and people evacuation

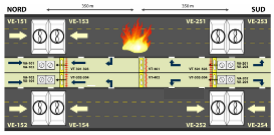
Option no.1
Longitudinale avec accélérateurs.



Option no.2 - Semi-transversale avec ventilateurs VA uniquement.



Option no.3
Semi-transversale avec ventilateurs VA et VE.



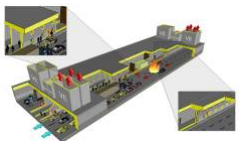
Option no.4
Semi-transversale avec séparations horizontales et 4 compartiments supérieurs

Option no.5
Semi-transversale avec séparations horizontales et multiples compartiments.

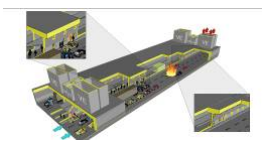
Option no.6
Semi-transversale avec quelques ouvertures murales obturées.

Option no.7
Semi-transversale avec séparations horizontales et 2 compartiments supérieurs.

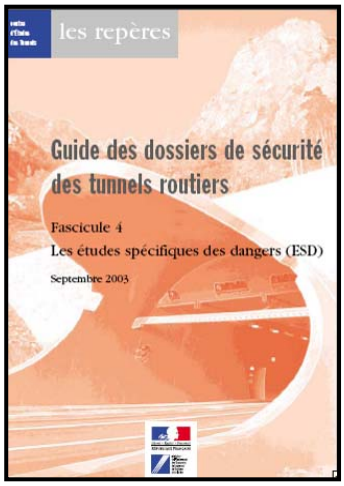
Option no.8 Longitudinale (Transitoire) avec ventilateurs VE à l'entrée et à la sortie

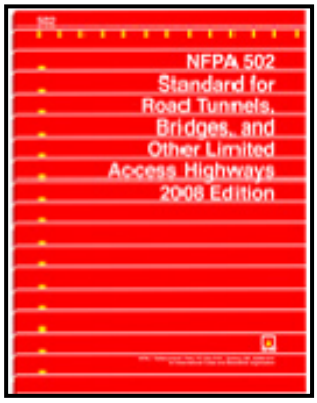


Option no.9 Longitudinale avec ventilateurs VE à la sortie (extraction massive)



Prescriptive VS Performance approach





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Objective and scope of the mandate

Previous work

In the last 10 years, over 42 M $ have been spent on rehabilitation and refurbishment of the tunnel and much more, still need to be done …

Scope of the mandate

Develop and document the best possible solutions that answers the required functions at the lowest possible life cycle cost, consistent with requirements, performance, maintainability, and safety.

- Hazard and Value Analysis including Risk Analysis
- Identify the performance criteria that meet safety requirements
- Find an optimize solutions that best meet the performance criteria
- Identifying solutions with the best potential at the lower cost

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VALUE ANALYSIS versus RISK ANALYSIS

SYSTEMATIC METHODOLOGIC APPROACH

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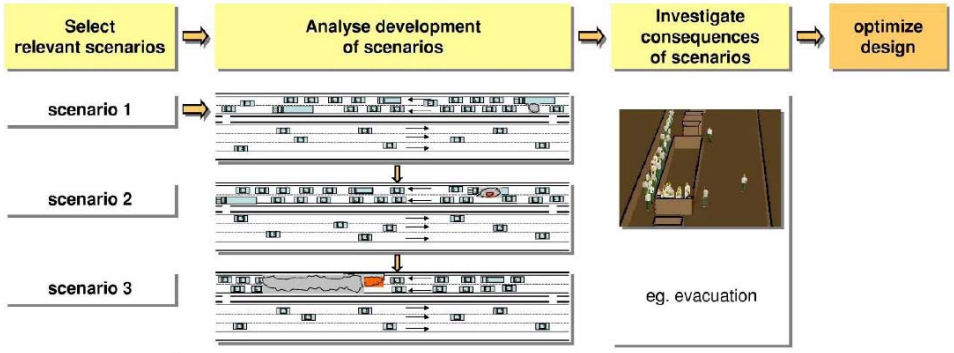
VALUE ANALYSIS versus RISK ANALYSIS

Risk analysis – Scenario based approach



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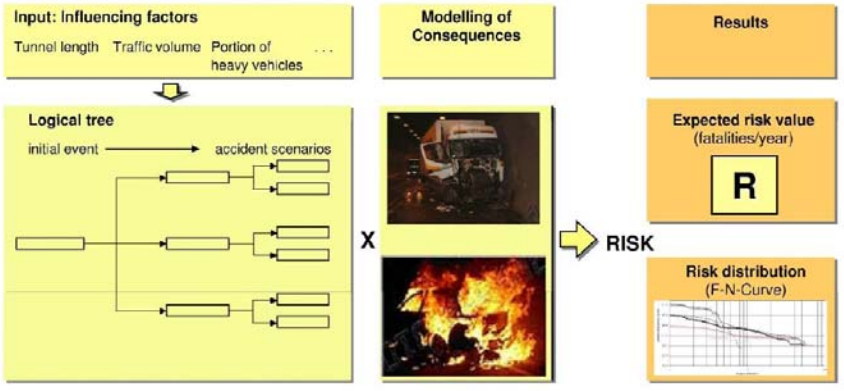
VALUE ANALYSIS versus RISK ANALYSIS

Risk analysis – System based approach



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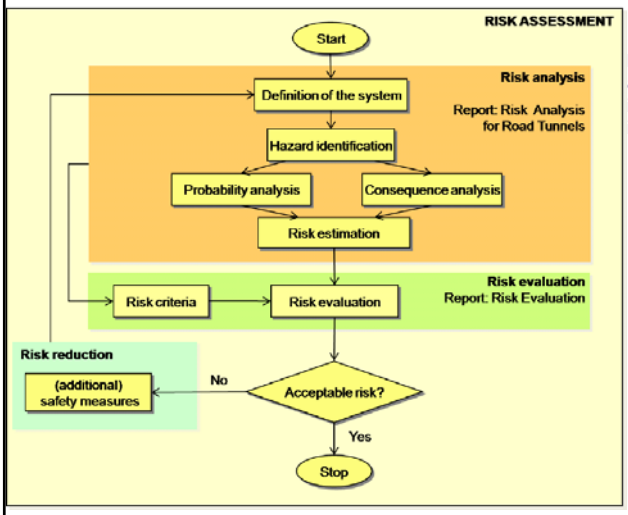
VALUE ANALYSIS versus RISK ANALYSIS



Risk analysis: Systematic approach to analyse sequences and interrelations in potential incident or accident, hereby identifying weak points in the system.

Risk evaluation: about acceptability of the identified risks and has to give an answer to the question «Is the risk acceptable?».

Risk reduction: If the estimated risk is considered as not acceptable, additional safety measures have to be proposed

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VALUE ANALYSIS versus RISK ANALYSIS

Hazard Analysis (risk assessment):

- Human organization of tunnel operational staff,
- Fires hazard and transport of dangerous goods,
- Terrorism and vandalism hazards,
- Technological and equipment failure,
- Road accident due to wrong drivers' behavior,
- Flood and sewer backup,
- Ventilation management and lighting,
- Climatic conditions,
- Oversized vehicles.

Value Analysis (achieve balance between 3 main principals):

- Answer all required functional needs and client priorities;
- Find a solution with the lowest cost and the best value;
- Fit in the required schedule and timeline;

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VALUE ANALYSIS versus RISK ANALYSIS

Methodology used:

1. Establishing the tree of safety functional needs
   - Operational needs in term of maintenance
   - Minimum requirements from NPFA 502 and CE 2003/2004
2. Evaluate Worst Case Scenario on existing tunnel
3. Establishing Performance Criteria for design
4. Brainstorming and creativity workshop
5. Optimization of the potentially “best” solutions
6. Value Analysis for choosing the optimal solution

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VALUE ANALYSIS versus RISK ANALYSIS

Participants to the workshop

Multidisciplinary team working together to achieve common objectives

- Transport Quebec Operational staff
- Transport Quebec maintenance staff
- Retired Transport Quebec staff
- Consultants in safety and ventilation
  - Civil and mechanical engineers
  - Architects and standards specialists
  - Cost and value specialists

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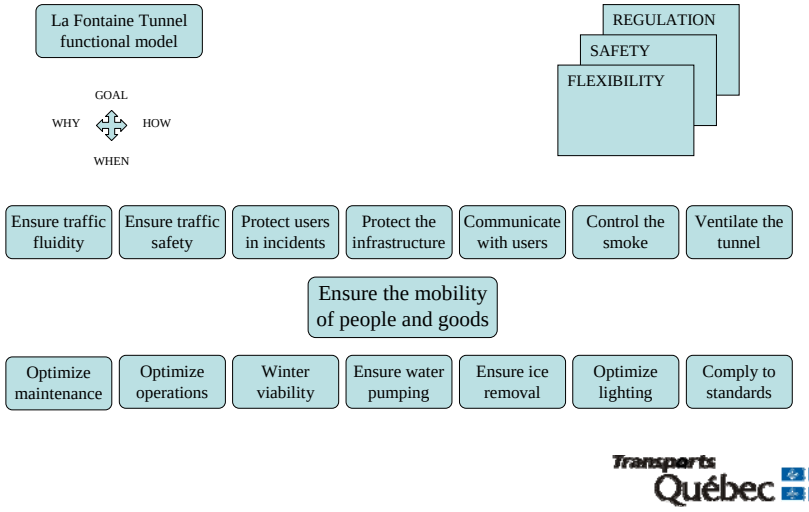
1. Tree of safety functional needs



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1. Tree of safety functional needs

FUNCTIONAL NEEDS

	Ensure traffic fluidity	Ensure traffic safety	Protect users in incidents	Protect the infrastructure	Communicate with users	Control the smoke	Ventilate the tunnel
F0 no flexibility *F4 more flexibility* FLEXIBILITY	F1	F0	F0	F1	F0	F0	F1
SCORE	7/10	7/10	4/10	7/10	3/10	7/10	6/10

	Optimize maintenance	Optimize operations	Winter viability	Ensure water pumping	Ensure ice removal	Optimize lighting	Comply to standards
F0 no flexibility *F4 more flexibility* FLEXIBILITY	F0	F0	F0	F0	F0	F0	F1
SCORE	6/10	5/10	4/10	6/10	7/10	7/10	4/10

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2. Worst Case Scenario Evaluation

Major incident corresponding to a 30MW fire in the centre of the tunnel after collision of 2 semi trailers with a stalled vehicle.

Inspired by: A. Voeltzel & A. Dix, 2004. *A comparative Analysis of the Mont Blanc, Tauren and Gotthard Tunnel Fires*. Routes-Roads # 324.

- Fire grew rapidly even if the lorry's load was not considered dangerous goods
- Difficulty in reaching and extinguishing the fire because of smoke and heat
- First firemen arrived from the most smoky side and couldn't reach the fire
- Fire-fighters arrived at the fire in the shortest time possible but the fire was already to large and difficult to fight
- Many users stayed in their vehicles and victims died asphyxiated in the smoke by lack of appropriate knowledge on how to behave in similar situations
- Car drivers entered the tunnel in spite of red signals by lack of appropriate knowledge on how to behave in similar situations
- Fresh air supply contributed in de-stratification of the smoke and backlayering was observed where the air flow velocity is practically zero

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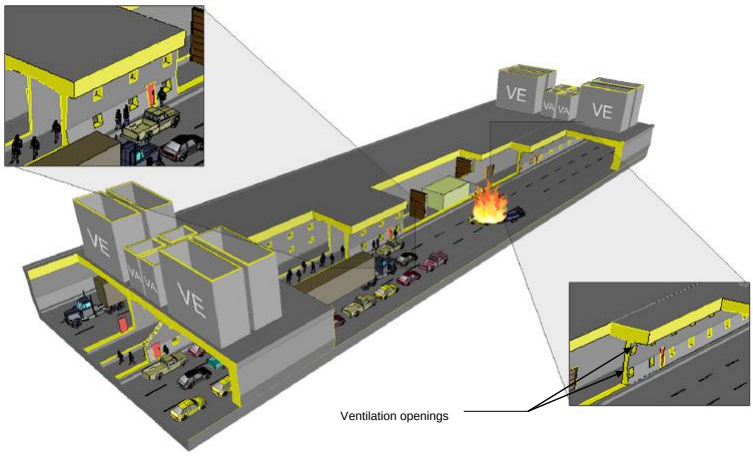
2. Worst Case Scenario Evaluation



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2. Worst Case Scenario Evaluation

FUNCTIONS TO BE IMPROVED

Communicate with users:

- Need to inform users on behaviour expected from them in case of fire;
- Need to communicate with users in real time during an event;
- Need to inform and educate users on tunnels and fire hazards;

Protect users in case of fire:

- Barriers should be considered to avoid accumulation of vehicles;
- Need to encourage self-evacuation in a very short period;

Ventilation and smoke control:

- Need to protect evacuation route from smoke;
- Avoid de-stratification of smoke and reduce backlayering;

Protect the infrastructure:

- Consider Fixed Fire Fighting Systems in reducing the fire growth
- Consider detection systems able to locate the fire precisely and quickly

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3. Performance criteria for design

CRITERIA	WEIGHT
USERS' SAFETY (visibility, signs, signals, etc.)	20
USERS' COMFORT (tunnel environment, lighting, etc.)	7,9
EMERGENCY EGRESS ACCESSIBILITY	8,7
CONSTRUCTIBILITY (feasibility, cost, etc.)	7,1
OPERABILITY (vulnerability to human errors)	8,1
MAINTENABILITY (easiness of maintenance)	7,3
TECHNOLOGICAL RISK (product maturity and efficiency)	6,7
LIFE CYCLE (long term adaptability)	7,4
SPEED OF PEOPLE EVACUATION	6,0
TRAFFIC MANAGEMENT (ease of traffic management)	10

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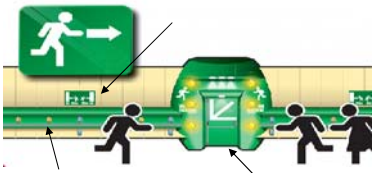
4. Brainstorming sessions (options)



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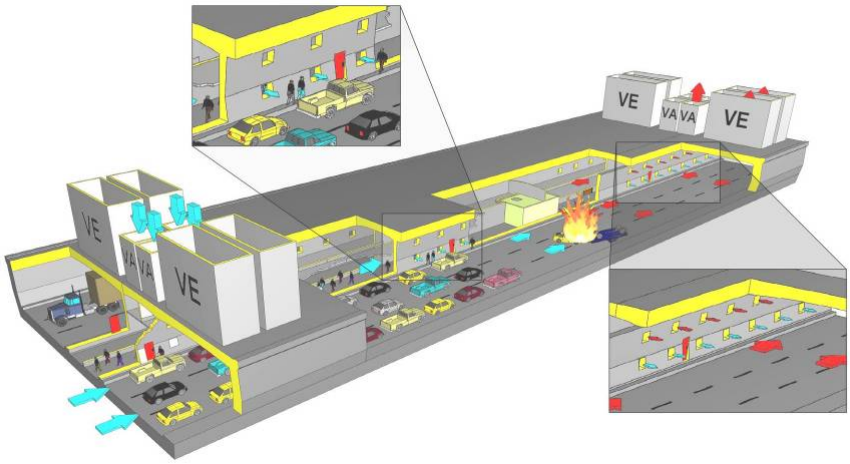
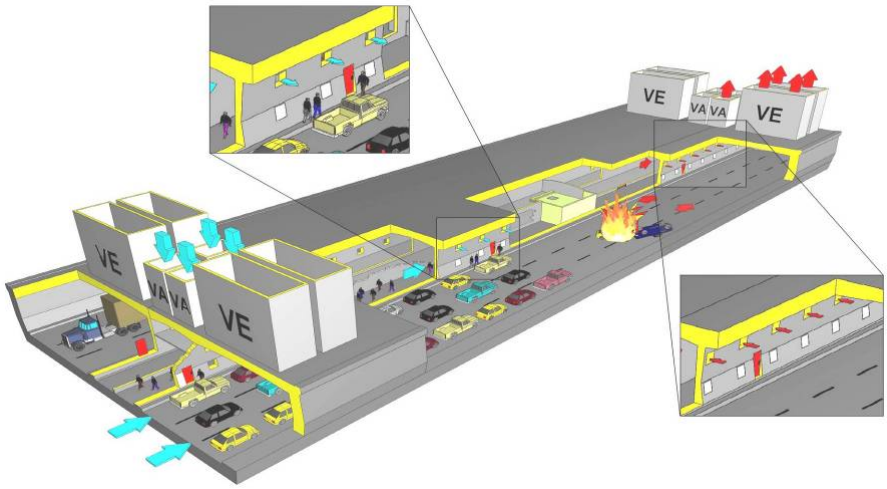
5. Optimization of the best options

Option 4



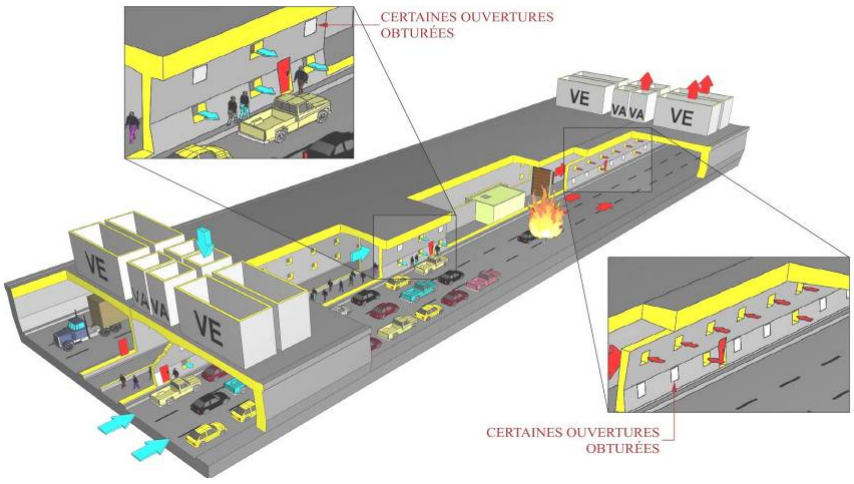
5. Optimization of the best options

Option 9



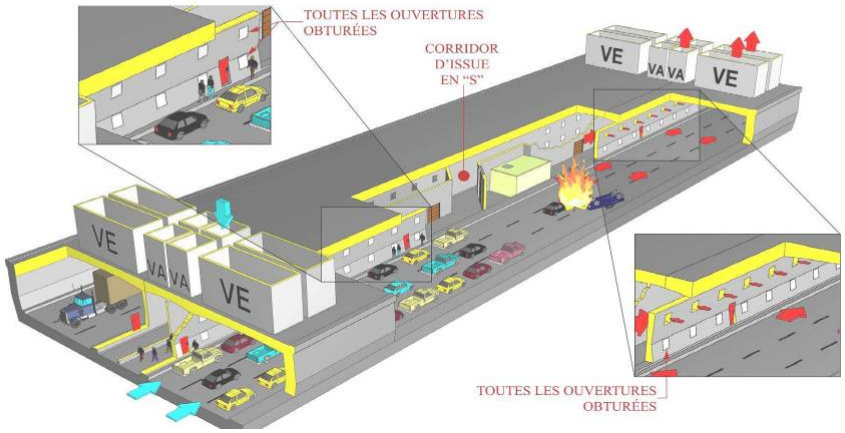
5. Optimization of the best options

Option 6



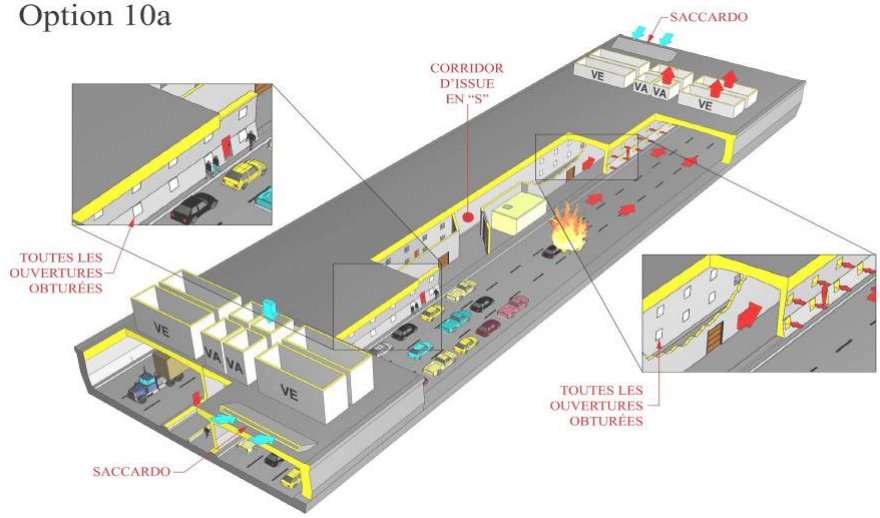
5. Optimization of the best options

Option 10



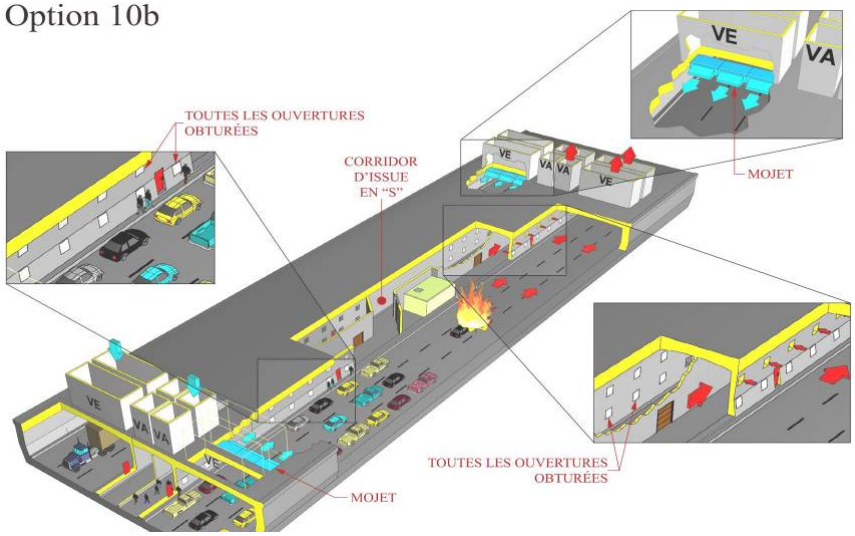
5. Optimization of the best options

Option 10a



5. Optimization of the best options

Option 10b



5. Optimization of the best options

PERFORMANCE ASSESSMENT

		PERFORMANCE CRITERIA										
	N°	1	2	3	4	5	6	7	8	9	10	
	Weight	20,0	7,9	8,7	7,1	8,1	7,3	6,7	7,4	6,0	10,0	
Description sommaire		SAFETY	CONFORT	EMERGENCY EGRESS	CONSTRUCTIBILITY	OPERABILITY	MAITENABILITY	TECHNOLOGICAL RISK	LIFE CYCLE	PEOPLE EVACUATION	TRAFFIC MANAGEMENT	**PERFORMANCE**
Existing situation with some improvements mainly in communication		6	7	4	10	7	1	6	7	6	7	61%
Existing situation with no improvements		5	7	2	1	4	4	7	7	4	1	42%
Option 4 : 2 floors in central tube + mid-tunnel division for semi-transverse ventilation		10	9	6	1	1	1	6	4	7	7	59%
Option 9 : 2 floors in central tube + mid-tunnel division for longitudinal ventilation		10	10	8	4	4	4	6	4	10	7	72%
Option 6 : upstream supply + downstream exhaust with openings balanced downstream		7	7	4	8	9	7	6	8	4	7	68%
Option 10 : evacuation route in S + more powerfull exhaust fans for longitudinal ventilation		8	9	8	8	9	8	6	7	8	7	76%
Option 10A evacuation route in S shape + Saccardo for longitudinal ventilation		9	8	8	7	10	7	6	8	8	7	80%
Option 10B corridor «S» (ventilateurs Mojet au puit des tours)		10	8	8	7	10	6	5	8	10	10	85%

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6. Value Analysis Results

PERFORMANCE versus COST

	Performance	Cost
Option 4 – 2 floors in central tube + semi-transversal ventilation	59%	**100%**
Option 9 – 2 floors in central tube + longitudinal ventilation	72%	**100%**
Option 6 – upstream supply + downstream exhaust + balanced openings	68%	**38%**
Option 10 – Corridor en S	**78%**	**33%**
Option 10A – Corridor en S + SACCARDO	**80%**	**55%**
Option 10B – Corridor en S + MOJET	**85%**	**46%**
Option 100 – Existing corridor + better signs and signals	61%	**24%**

OPTION 100 includes equipment to improve human behaviour under normal and emergency situations.

OPTION 100 is included in all other options as being minimum needed requirements (cost included in other options).

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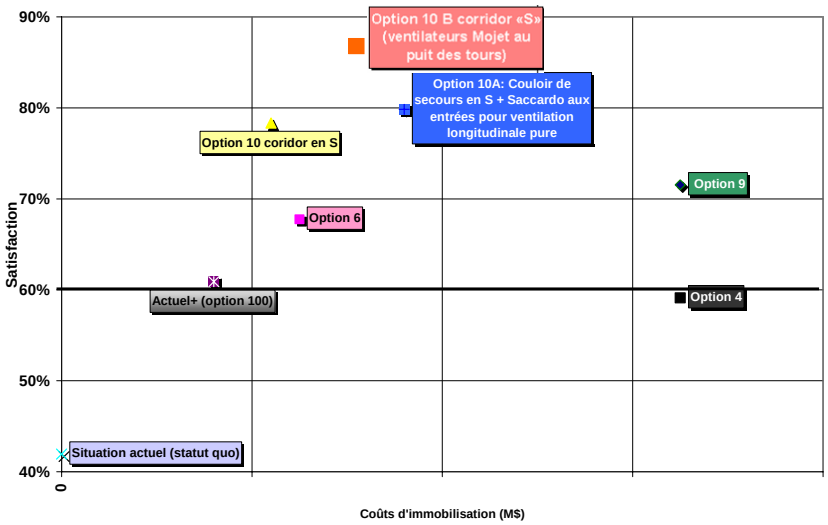
6. Value Analysis Results



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6. Conclusions et lessons learned

Conclusions:

- Solutions 10, 10A, and 10B give the best value and have an interesting potential to meet safety requirements and maintainability;
- Future studies need to further investigate these potential solutions to verify technical feasibility and optimize the design

Lessons learned:

- Need to have a Systematic Integrated approach for tunnel safety upgrade including a risk assessment process (risk analysis + risk evaluation), combined with a value analysis or value engineering process;
- Need to have the active participation of all key actors in the project, beginning with the infrastructure owner, operators, project managers in a multidisciplinary team working together on a commonly defined objective;
- Need to keep a focus on achieving the requirement at the best value;
- Need to argue and criticize but in an appropriate and respectful way.

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Merci de votre attention

Avez-vous des questions ?

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Contact

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