Chongqing PIARC – TESC seminar
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Experience of upgrading safety of existing tunnels

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introduction

new requirements
financial aspects
other safety factors

introduction

- Disasters 1999 and 2000 in Europe
  - ⌘ road tunnels : Mont Blanc – Tauern – Gotthard
  - ⌘ Kaprun ski resort funicular
- Lead to a huge emotional shock for
  - ⌘ the alpine countries population
  - ⌘ the all European community
- Alpine countries governments, then European Union
  - ⌘ launched critical analysis of tunnel safety existing standards
  - ⌘ decided to noticeably upgrade the tunnel safety level
  - ⌘ and impose new challenging requirements as
    - French Instructions (August and December 2000)
    - European Directive (April 2004) transposed in the legislation of each European country
      - new requirements and deadlines

introduction

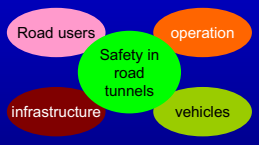
- New requirements and deadlines
  - ⌘ Initially for
    - TEN (Trans European Road Network)
    - national motorways and highways
  - ⌘ then also introduce for
    - regional and local roads
    - urban tunnels
- A similar approach (less structured) is currently done in some countries for
  - ⌘ the tunnels of rail networks
  - ⌘ the tunnels of waterways networks

introduction

- Financial view
  - ⌘ some countries have number of tunnels that have to be upgraded – about 1.000 in Italy for example
  - ⌘ upgrading represents an very important budget
  - ⌘ a strategy has to be developed in order
    - to define a hierarchy of priority between the diverse tunnels
    - to introduce for each tunnel eventual upgrading stages, associated to a ratio of benefit of each stage upgrading / cost
- Some example of upgrading budget
  - ⌘ upgrading costs are in a range of
    - 15 / 20 Mio € for very simple and short tunnels
    - to 500 Mio € - Mont Blanc tunnel
    - at present several tunnels in the range 100 Mio € / 200 Mio € under upgrading works

introduction

- Don't forget that
  - ⌘ infrastructure is only a part of the global tunnel safety
    - you may invest a lot money without to slightly improve the safety if you are not simultaneously improving
      - operation procedures
      - staff training
      - emergency services training



  - ⌘ if the upgrading target for the infrastructure is financially asymptotic / versus safety improvement
    - you may choose a less challenging infrastructure target
    - and concentrate much more effort on the others safety factors

frame and methodology for upgrading

standards and legal frame
diagnosis - inventory and statement
safety and danger study
external constraints

foreword

- Presentation focuses on safety upgrading
  - ⌘ heavy repairs are another field and present other constraints
- Each tunnel is different from the other
  - ⌘ project needs to be adjusted to the specific context
    - aim at the optimal Risk-Safety-Cost-Time combination
    - requires a multidisciplinary approach
    - involves a complex and iterative process
  - ⌘ recipes cooking book do not exist – but common methodology
- Main stages of the methodology
  - ⌘ standards and legal frame
  - ⌘ diagnosis - inventory and statement of tunnel state
  - ⌘ safety and danger study
  - ⌘ external constraints
  - ⌘ upgrading project

standards and legal frame

- Choice of standards or directives to be apply
  - ⌘ several countries do not have standards or updated standards for tunnel safety
    - choice of foreign standards in order to have
      - improved incontestable technical referential
      - strong statement in case of eventual judicial proceedings
    - never stay without any standard
    - do not invent your own standard
  - ⌘ for countries with updated national standards
    - national standards are usually not mandatory for local roads and urban roads
      - choice basically your national standards
      - do not invent a particular degraded standard
        - the choice to voluntary expose the users to low safety conditions will be indefensible in case of judicial proceedings

standards and legal frame

- Legal or administrative frame
  - ⌘ European Directive, national instructions in Europe (still complementary used when they are more demanding), fix a legal frame for
    - Compulsory participation of "officially recognised experts"
    - Submitting the project to a special national body
    - approving the project by the administrative Authorities
  - ⌘ In case of using foreign standards control of
    - Acceptation by administrative Authorities
    - Possibility of transposition (with adjustments) of the legal or administrative frame

standards and legal frame

- During the project development for a tunnel safety upgrading, you have to
  - ⌘ face difficult choices
  - ⌘ to arbitrate between complex and contradictory conditions
  - ⌘ with bearing a great responsibility, even a judicial one, in case of a future disaster
- It is the reason why
  - ⌘ project must be settled on improved standards
  - ⌘ arbitration and choices have to be discussed and shared with highly experimented experts

standards and legal frame

- Fundamental safety objectives have to be listed
  - ⌘ As example main but not exhaustive objectives
    - Detection of abnormal situations - Communication to users

Supervision and detection means (AID, FD, CTCS)
Stoppage detection and closing signaling
Stopping and closing devices
Emergency Telephone Systems

    - Protection and Evacuation of Users - Access by Emergency Services

Evacuation, protection and access devices
Accessibility to Reduced Mobility Persons
Ventilation design and management
Safety lighting quarantining

    - Fire Protection and Fighting

Fire stability and resistance
Upgrading and securing fire fighting equipment
Ventilation design and management
Water collection (slotted ducts and storage tanks)

diagnosis

- Inventory and statement of tunnel state
  - ⌘ unattractive stage
  - ⌘ but essential, and to be done with meticulous care
  - ⌘ experience shows that a lack of this stage or superficial inventory lead to
    - makeshift job all along the project and the works, to face the unknown situations and the hazards
    - pour quality, and unpredictable upgrading result
    - financial slides
    - impossibility to keep the deadline

inventory and statement

- Updating of “as built drawings”
  - ⌘ escape routes – equipments – safety tools
  - ⌘ very often lack of “as built drawings”
  - ⌘ tunnel is alive
    - modification and additional equipments or functions
- Investigation of the state of the equipments
  - ⌘ age – working state – maintenance – functioning problems – existence of spare parts – etc.
  - ⌘ localisation – protection
- Protection against the fire
  - ⌘ protection of the structure and the equipments
  - ⌘ fire fighting equipments

inventory and statement

- Performance and reliability of the equipments
  - ⌘ check real performance : ventilation – transmission network – CCTV – etc.
  - ⌘ evaluation of reliability
- In case of supervision room and SCADA
  - ⌘ redundancy – minimal conditions for operating
  - ⌘ performance – functional analysis - automatically scenarios - transmission chain –
  - ⌘ interface man / computer - ergonomy

inventory and statement

- In brief, the target is to have a
  - ⌘ Very detailed picture of the situation
    - In order to have a good base for the design and to be able to determine
      - What is missing and has to be completed
      - What as to be reinforced, protected, improved - etc
  - ⌘ Precise performance state of all the equipment
    - In order to be able to determine if the performances are sufficient or if they have to be increased
  - ⌘ Detail situation of the age and the functioning conditions of the equipments
    - In order to be able to determine if some equipments have not to be renewed during upgrading process, even if they are still complying with their function and the required performances

safety and danger study

- The tunnel after upgrading process
  - ⌘ will have to comply to the standards
  - ⌘ but also to face the specific local conditions
- Safety and danger study is required by the standards
  - ⌘ allows the analysis of specific local conditions
  - ⌘ but is also a very performing tool
    - for the design and the optimisation
    - for helping you in front of difficult choices or arbitration
  - ⌘ safety and danger study includes
    - risk analysis
    - response plan in case of emergency
  - ⌘ refer to detailed presentations by Juergen Krieger and Rudolf Hoerhan

safety and danger study

- Safety and danger study
  - ⌘ has to be carried out (detailed or preliminary analysis according to the different stages)
    - considering the situation before upgrading
      - in order to eventually take particular temporary operating conditions, if the risk level is too high
        - crossing forbidden for tucks and vans – many examples
    - for the tunnel during two upgrading stages if the local conditions oblige to temporary reopen the tunnel
      - particular operating conditions to mitigate the risk
        - for examples: fire brigade or road safety patrols
    - for the tunnel after upgrading
      - to determine the upgrading program
      - to renew operating and emergency procedures

external constraints

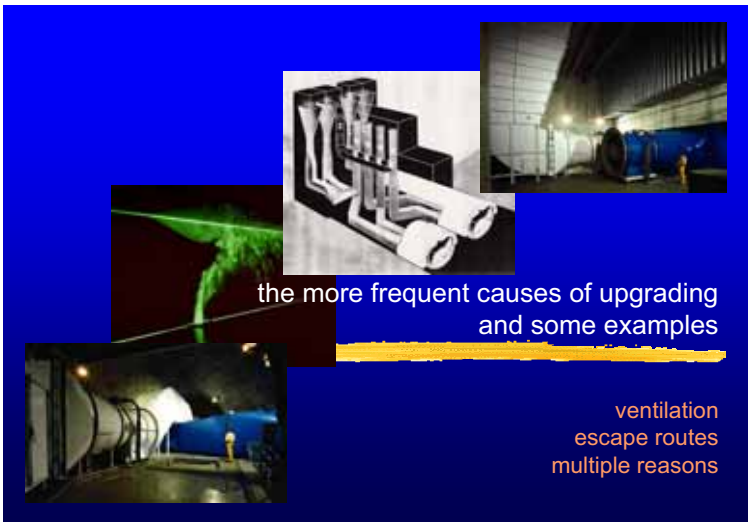
- Traffic is the more significant external constraint
  - ⌘ tunnels under operation provide
    - an economical function
    - a service for the community
  - ⌘ traffic volume may be very high
    - 70.000 to 110.000 v/day (several examples under upgrading)
    - can not be easily transfer to another route
  - ⌘ tunnel closing may be a huge handicap
    - for the users and the economy
    - even closing one of both tubes may have very important consequences : several recent examples with daily queuing of 10 km and 60' waiting time for motorway tunnel upgrading

external constraints

- Impact on traffic has to be carefully considered with
  - ⌘ consequences on the design
    - eventual concept modification and cost increase
  - ⌘ strategy for doing the works
    - dividing the works in different stages or periods according to traffic peak, to day / night period, to holidays periods
    - reducing the closing period
      - accurate and very detailed method analysis
      - eliminate any hazards
        - importance of detail inventory and statement
        - organisation - risk analysis for mitigating the works
      - top organisation and follow up to gain time (each hour is important)
    - necessity to use new technology, more powerful machinery, continuous working teams, with financial consequences

upgrading design

- Design is the result of
  - standards and legal frame
  - inventory and statement of tunnel state
  - safety and danger study
  - external constraints particularly traffic
  - and according to the tunnel conditions
    - define a safety/renovation program both reliable and realistic
    - if needed arbitrate with a judicious balance between all the factors making a road tunnel safe
- There are many ways towards an improved safety
- Each tunnel upgrading needs to be adjusted to the specific context of the project



the more frequent causes of upgrading and some examples

ventilation
escape routes
multiple reasons

more frequent causes and examples

- The list below is not exhaustive
  - but only to give some examples and to show case by case that the solutions may be very wide
    - dewatering
    - signalling
    - fire protection
    - ventilation
    - escape routes
    - multiple - reasons

dewatering

- Construction of slot gutter with siphon
  - objective
    - reduce the pavement surface spread in case of gas leakage
    - reduce the fire power
    - avoid fire spreading inside dewatering system
  - construction conditions
    - construction possible during night with closing a lane
    - low consequences on traffic
    - low inconvenience for users
    - temporary reinforcement of signalling and patrol
- Construction of storage tanks
  - objective
    - safety improvement at portals
    - environmental protection of water resources
  - construction conditions
    - construction outside of traffic space
    - no inconvenience for users
    - temporary reinforcement of signalling and patrol

signalling

- Complementary signalling
  - objective
    - improve signalisation and communication with the users
    - improve guidance to escape routes
    - improve traffic management
  - construction conditions
    - signalling on the side wall: construction possible during night with closing a lane
    - signalling above traffic space: preparation out side – installation during night with a short closing of the tube during lifting and fixing
    - cables for supply and remote: during night with a lane closed
    - low consequences on traffic
    - low inconvenience for users
    - temporary reinforcement of signalling and patrol
    - test during low traffic periods

fire protection

- Fire protection of the structure – the cables
  - objective
    - Protection of the structure
    - Protection of the cables
  - construction conditions for structure protection
    - In case of complex work associated with civil heavy repairs : closure of a tube is needed
    - In case of fixing protection plates, or shooting a protection system : during night with a lane closed
    - consequences on traffic
  - construction conditions for cable protection
    - Construction of a trough
    - Usually complex : cables have to be temporary removed – their functions has to be kept
    - Construction is partly possible during night time and closure of a lane (usually associated with slot gutter construction)
    - A part of the work requires tunnel closing. Closing period depends to method and organisation
    - consequences on traffic
    - inconvenience for users

ventilation

- May be very simple or very complex
  - ⌘ simple – unidirectional tunnel 2 tubes
    - existing ventilation is longitudinal
    - traffic increase and fire conditions require more air flow or higher air flow velocity (5 m/s for hazardous goods)
    - solution is to add complementary fans
      - new fans may be installed during very short tunnel closure
      - complementary power supply may be install during night with one lane closed
      - modification of SCADA may be tested during low traffic period
    - upgrading needs a good preparation, a good organisation, but can be done without too much impact on traffic conditions, safety and comfort for the users

ventilation

- May be very simple or very complex (continuation)
  - ⌘ more complex – unidirectional tunnel 2 tubes
    - existing ventilation semi transverse but tunnel have to face
      - numerous traffic jams
      - particular atmospheric conditions at portal, with consequence strong natural air current inside the tunnel
    - upgrading requirements
      - control and manage air velocity
      - keep smoke extraction
    - solution is to control the air current with jet fans or injectors
      - refer to my presentation concerning ventilation with some examples
      - if solution is to install jet fans in the vault
        - need to build localized recess with local reducing of air ducts in order to install jet fans

ventilation

- more complex – unidirectional tunnel 2 tubes (continuation)
  - if solution is to install jet fans in the vault
    - need to build localized recess with local reducing of air ducts in order to install jet fans
    - installation of jet fans
    - power supply increase – data transmission network extension
    - SCADA modification
  - organisation of upgrading works
    - civil for recess needs closure of the tube
    - others works as for previous example
  - strategy for civil
    - investigation of all possible conditions
    - very detailed construction method analysis, in order to fix construction time with precision of less than one day
    - strategy of works staging with consideration of closing possibility

ventilation

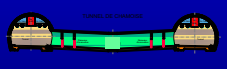
- more complex – unidirectional tunnel 2 tubes (continuation)
  - strategy for civil
    - in case of staging – evaluation of the safety conditions when temporary reopening between to construction stages
    - tight survey and control of the upgrading works in order to absolutely respect the time schedule – look at any organisation opportunity to reduce this schedule
  - one example – Chamoise tunnel – 3,3 km – 2 tubes
    - dewatering – cables remove for protection – ventilation with 8 recesses each tube – pavement and painting
    - 5 stages of 6 to 10 weeks
    - low traffic periods out of winter period
    - each period duration fixed after a detailed traffic forecast analysis, and the works program to be done
    - each stages reopened with 1 to 3 days in advance

ventilation

- may be very simple or very complex (continuation)
  - very complex
    - upgrading works are usually not only concerning ventilation, but also escapes routes
    - see two examples following examples
  - the more complex and complete upgrading ventilation system is for Mont Blanc tunnel
    - see my other presentation relating to ventilation

escape routes

- Creation of complementary escape routes needs civil works that may be very complex and costly
- Twin tubes tunnel
  - Construction of additional connexion galleries
  - Good ground conditions
    - closing a tube is acceptable during the night
      - no particular difficulties
      - method and organisation in order to reopen each morning at time
    - closing a tube not acceptable
      - construction during the night
      - closure of left lane and width reduction of right lane
      - short temporary full closure
      - top methods, organisation and control are required



escape routes

- Twin tubes tunnel
  - ⌘ bad ground conditions – under water table
    - If grouting or freezing methods are required
      - Impossible to construct connection gallery without closing a tube for a long time, unless possible works from the surface
      - If closing a tube is not possible
        - investigate other solutions which could be bring a similar level of safety,
        - with eventual improvement and reinforcement of other factors or equipments, that do not require upgrading : ventilation management – smoke extraction – traffic management – etc.

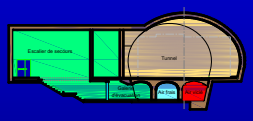
escape routes

- Tunnel with unique tube
  - ⌘ 3 tunnels – 3 examples – 3 different solutions
- Mont Blanc – 11,6 km
  - ⌘ construction of new safety shelters – spacing 300 m
  - ⌘ parallel gallery as escape route from the shelters
    - has been investigated, but solution not adopted
      - too long construction time (11,6 km)
      - very expansive
      - no major advantage with the chosen solution
  - ⌘ chosen solution: use of the fresh air duct as escape route
    - special connections needed from escape shelters
    - particular operating procedures
  - ⌘ tunnel was closed for refurbishment

escape routes

- Mont Blanc

TUNNEL DU MONT-BLANC



escape routes

- Puymorens tunnel – 4,8 km
  - ⌘ Existing situation
    - Low traffic : < 2.500 veh/day – very few trucks and buses
    - Reversible semi – transverse ventilation with two plants
    - Existing safety shelters with fresh air supply from portal
  - ⌘ Investigation of a parallel small gallery as escape route
    - Solution not adopted : too expansive
  - ⌘ Investigation of 2 connection galleries with rail tunnel
    - Solution not adopted
      - distance 400 / 500 m To control
      - Difficult to construct long galleries from existing tunnel without important constraints on traffic and operation
      - Intervention inside rail tunnel requires special train
      - 4 shelters remain without escape

      To control

escape routes

- Puymorens tunnel – 4,8 km
  - ⌘ chosen solution
    - reinforcement of shelters fire protection
    - reinforcement of shelters fresh air supply
    - upgrading smoke exhaust with additional remote and motorised smoke exhaust dampers
    - regulation and control of truck and bus traffic
      - limitation of trucks and buses together inside the tunnel
      - construction of a regulation plaza on the north portal
      - used for regulation the toll plaza close to south portal
  - ⌘ solution ware possible thanks low trucks and bus traffic
    - regulation of truck and bus traffic
      - reducing the number of people trapped in the shelters
      - lowering the fire power and the risk level

escape routes

- Puymorens tunnel – 4,8 km

multiple-reasons

- Maurice Lemaire tunnel – 7 km
  - ⌘ existing situation
    - old rail tunnel (1930) transformed (1976) in road tunnel
    - semi transverse ventilation with plants at portals, and precasted segments hanged in the vault for ducts
    - no safety shelters – no escape route

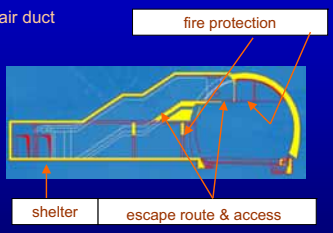
multiple-reasons

- Maurice Lemaire tunnel – 7 km
  - ⌘ existing situation
    - Insufficient vertical clearance
    - Corrosion of the anchors and the corbels supporting the ventilation ducts – risk of segments fall
    - Management and control of the air current inside the tunnel
    - Impossibility to survey the vault – and very difficult to make maintenance and reinforcement works
  - ⌘ Three main alternatives have been investigated

multiple-reasons

- Maurice Lemaire tunnel – 7 km
  - ⌘ alternative 1
    - Shelters and escape using fresh air duct
    - other improvements not possible

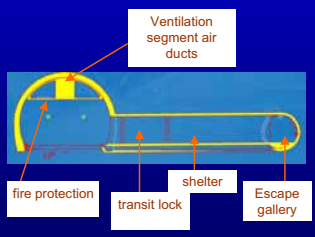
alternatives	1	2	3
Shelters			
Protected escape			
Vertical clearance			
Risk of segments fall			
Air current control			
Survey and vault maintenance			
Increase of ventilation performance			



multiple-reasons

- Maurice Lemaire tunnel – 7 km
  - ⌘ alternative 2
    - shelters and parallel escape gallery
    - other improvements not possible

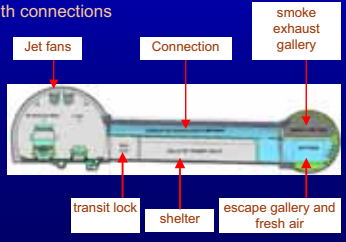
alternatives	1	2	3
Shelters			
Protected escape			
Vertical clearance			
Risk of segments fall			
Air current control			
Survey and vault maintenance			
Increase of ventilation performance			



multiple-reasons

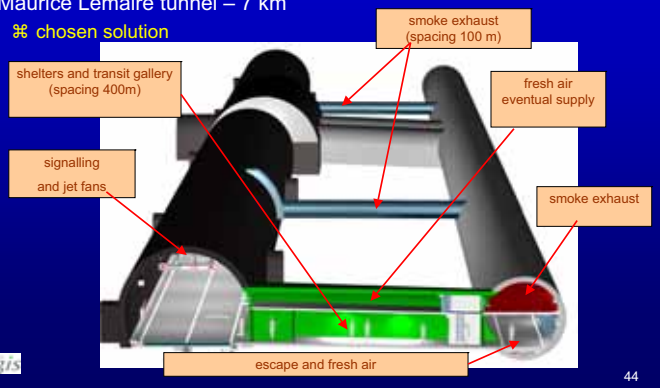
- Maurice Lemaire tunnel – 7 km
  - ⌘ alternative 3
    - shelters and parallel escape gallery
    - taking down segments
    - jet fans to control air current and smoke spreading
    - air duct in the parallel gallery with connections

alternatives	1	2	3
Shelters			
Protected escape			
Vertical clearance			
Risk of segments fall			
Air current control			
Survey and vault maintenance			
Increase of ventilation performance			



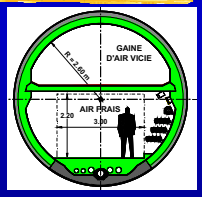
multiple-reasons

- Maurice Lemaire tunnel – 7 km
  - ⌘ chosen solution



multiple-reasons

- Maurice Lemaire tunnel – 7 km
  - very high risk level in case of fire
    - tunnel closed to trucks before upgrading
    - traffic diversion routes as been organised
  - closing of existing tunnel for the works
  - 200 Mio € investment

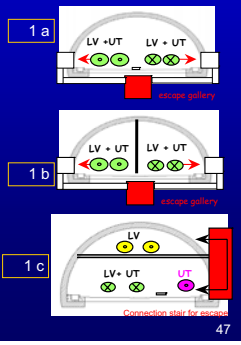


multiple-reasons

- Urban tunnel in France – 1.750 m
  - characteristics
    - in operation since more of 50 years
    - 4 lane bi-directional traffic in one unique tube
    - 60.000 veh/ day with everyday traffic jams
    - transverse ventilation with 5 shafts
  - after diagnosis and preliminary risk analysis
    - very low maintenance level
    - very poor conditions of the tunnel
    - important risk of air ducts fall in case of fire
    - lack of escape
    - as consequence:
      - decision to forbid vans and trucks to drive through the tunnel – risk mitigation measure

multiple-reasons

- Urban tunnel in France – 1.750 m (continuation)
  - three families of solutions have been investigated with consideration of
    - upgrading safety level
    - general tunnel renovation
    - taking in account urban development
  - family 1
    - space reorganisation of cross section
    - escape gallery
    - ventilation concept modification



LV = light vehicles
UT = urban transport

multiple-reasons

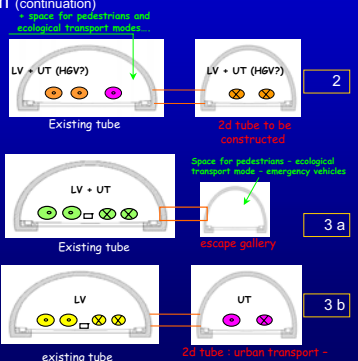
- Urban tunnel in France – 1.750 m (continuation)
  - family 2
    - uni-directional traffic

2d tube used temporary for traffic diversion during the upgrading works

  - family 3
    - bi-directional traffic

For solution 3b: 2d tube used temporary for traffic diversion during the upgrading works

LV = light vehicles
UT = urban transport



multiple-reasons

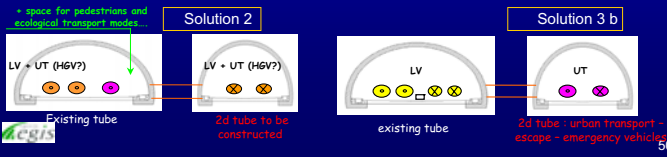
- Urban tunnel in France – 1.750 m (continuation)
  - ⌘ comparison criteria

Very favourable
Medium favourable
Less favourable

	1 a	1 b	1 c	2	3 a	3 b
functionality						
potential of additional facilities						
traffic disturbance during works						
safety level under operation						
operation conditions after upgrading						
connections to existing roads						
environmental impact during works						
upgrading costs						
duration of tunnel closure in years	1,5	1,5	2,0	0,15	0,15 (1,5 year with 2x1 lane)	0,15

multiple-reasons

- Urban tunnel in France – 1.750 m (continuation)
  - ⌘ Choice of solution
    - Construction of a new parallel tunnel 2 lanes in order
      - essentially to keep the traffic on 2x2 lanes during the works
      - with exception of 2 month closing in low traffic period (night and holidays) to take down ventilation duct
      - To offer a better safety level
    - Choice between solution 2 and 3 b will be done after more detailed analysis with consideration of the urban development master plan and transportation strategic plan



conclusions

- Tunnel upgrading may be very complex and costly
- Carefully stages of analysis must be done
  - ⌘ standards and legal frame
  - ⌘ diagnosis - inventory and statement of tunnel state
  - ⌘ safety and danger study
  - ⌘ external constraints – essentially traffic and environment
  - ⌘ upgrading project
- Traffic and traffic management during the works may have a crucial impact on the design
- Each tunnel is different from the other and requires a special approach

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Thank you for your attention