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High-Speed Rail Authority

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May 17, 2013

The Honorable Mark DeSaulnier, Chair
Senate Transportation and Housing Committee
State Capitol, Room 2209
Sacramento, CA 95814

The Honorable Mark Leno, Chair
Senate Budget and Fiscal Review Committee
State Capitol, Room 5019
Sacramento, CA 95814

The Honorable Bonnie Lowenthal, Chair
Assembly Transportation Committee
1020 N Street, Room 112
Sacramento, CA 95814

The Honorable Bob Blumenfield, Chair
Assembly Budget Committee
State Capitol, Room 6026
Sacramento, CA 95814

Dear Senator DeSaulnier, Senator Leno, Assembly Member Lowenthal, and Assembly Member Blumenfield:

In April 2012, the California High-Speed Rail Authority (Authority) released an estimate of the high-speed rail project's operating and maintenance (O&M) costs as part of the Authority's 2012 Business Plan.

In May 2012, the Authority asked the Union of International Railways (UIC) to provide a review of the O&M cost methodologies to ensure that the results were reasonable. The UIC report, entitled "UIC Peer Review of Operating & Maintenance Costs of the California High-Speed Rail Project," was finalized on March 31, 2013.

In completing its report, the UIC performed a comprehensive review of the Authority's O&M cost model used to develop the Authority's 2012 Business Plan. The UIC established a team of individuals experienced in the field of high-speed rail O&M cost development from several international high-speed rail operators. The UIC's findings concurred with most of the assumptions used in forecasting the Authority's O&M costs, and found the Authority's model to be sound.

The UIC experts furnished a list of nineteen constructive recommendations to continue improving the O&M cost estimating methods and assumptions. These recommendations are being reviewed and, as appropriate, will be incorporated into the O&M forecasts being developed for the Authority's 2014 Business Plan.

As required under Provision 9 of Item 2665-306-6043 of the Budget Act of 2012 (SB 1029, Chapter 152, Statutes of 2012), the Authority shall "submit a copy of the study by the Union Internationale des Chemins de Fer (the International Union of Railways) examining how the authority's estimated operating costs for high-speed rail compare to high-speed rail systems in other countries."

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For your review, the Authority has included a copy of the complete UIC report. If you have any questions, please contact Matt Robinson, Deputy Director of Legislation, at (916) 324-1541 or matthew.robinson@hsr.ca.gov.

Sincerely,

Jeff Morales

Jeff Morales
Chief Executive Officer

Attachment

cc: The Honorable Darrell Steinberg, President pro Tem, California Senate
The Honorable John Pérez, Speaker, California Assembly
The Honorable Ted Gaines, Vice Chair, Senate Transportation and Housing Committee
The Honorable Bill Emmerson, Vice Chair, Senate Budget and Fiscal Review Committee
The Honorable Eric Linder, Vice Chair, Assembly Transportation Committee
The Honorable Jeff Gorell, Vice Chair, Assembly Budget Committee

INTERNATIONAL UNION
OF RAILWAYS

unity, solidarity, universality

UIC PEER REVIEW

OF OPERATING & MAINTENANCE COSTS

OF THE CALIFORNIA HIGH-SPEED RAIL PROJECT

FINAL REPORT

MARCH 31, 2013

This peer review has been prepared by:

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UIC is the solely responsible for this document in the reference framework towards CHSRA.

Paris, 31st March, 2013

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Executive Summary

In April 2012, the California High-Speed Rail Authority (CHSRA) prepared an estimate of the high-speed rail (HSR) Operating & Maintenance (O&M) costs for the California High-Speed Rail Program's 2012 Business Plan.

In May 2012, CHSRA asked the Union of International Railways (UIC) to provide advice and comments about the O&M costs calculation. The UIC then proposed to set up a peer review, gathering experts from France, Italy, and Spain (the experts) who have significant experience in implementing and operating HSR projects.

UIC's Independent Review of the O&M Costs Study

As assigned by the UIC, the experts—supported by UIC representatives—conducted an independent review of the O&M costs that were estimated for the 2012 CHSRA Business Plan.

Scope of UIC's Independent Review

The experts' review focused on the methodology and the procedures developed by the CHSRA, as well as the resulting costs. The independent peer review did not aim to produce another O&M cost estimate; instead, the review was conducted to evaluate the soundness, validity, and reasonableness of the process, approach, assumptions, and variables used in the O&M cost study.

In order to improve the O&M cost modeling process developed by the CHSRA, the review also provided best practice guidelines and some European benchmark values that were based on the experts' experiences in building, operating, and maintaining European HSR systems.

Results of the Independent Review

The review suggests the following regarding the O&M modeling process:

The experts did not find any fatal flaws on the O&M cost process.

Overall Approach Used

The experts found that the CHSRA used a standard approach to define the following:

- An operating plan based on ridership forecasts
- A comprehensive detailed breakdown of the O&M costs by category and unit
- Sensitivity tests

It should be mentioned that the experts did not review the ridership process and did not have to produce any comments on the ridership results.

O&M Forecasts' Validity

It is the experts' view that the O&M costs' preparation was thorough. However, it should be recognized that the preparation was not a strictly statistical exercise.

Opinions and judgment also play a role in the forecast elaboration. Therefore, it is recommended that the CHSRA identify high/low scenarios of O&M costs and perform all the

necessary related cross checks; the time period for which the business plan is prepared is long and it is hard to foretell what would happen in such a long time frame.

Reasonableness of the Forecasts

The experts examined each major procedure/assumption and provided 19 findings (both favorable and constructively negative) regarding data, hypothesis, and procedures to enhance the O&M cost model. The experts have not appraised the impact of these findings on the business plan since it is the CHSRA management team's responsibility.

The experts have five primary areas of concerns for the model, which, if founded, individually or together would cause the O&M cost estimates to vary:

- A cost estimate for marketing and advertisement should be added as a specific effort while implementing the project and during the first 3 to 5 years.
- Distribution and sales costs should be revised based on the expected distribution mix between the various distribution channels.
- Further adjustment in infrastructure maintenance and rolling stock maintenance costs should be made to reflect the impact of trains operating at 220 mph (350 Km/h), keeping in mind that for energy consumption, simulations have been made.
- The consistency between the ridership forecasts and the operating plan needs further refinement to take into account a more detailed seasonality of the demand in the next enhanced phase of the business plan.
- By contrast, the O&M costs might be further reduced by optimizing the project and the operating plan.

The experts also agreed to provide relevant reference unit costs derived from their European experience for infrastructure and rolling stock maintenance since there is no possible analogy with any U.S. HSR system currently in operation. They thus provided some European benchmarked costs.

In the view of the experts, these proposed guidelines should be a key input to the O&M cost model the CHSRA is responsible for.

1 O&M COST REVIEW INITIATION AND OBJECTIVES

The primary objective of the peer review was both:

- To evaluate the overall process, individual procedures, and assumptions prepared by the CHSRA project management team, and used for the CHSRA 2012 Business Plan for technical validity.
- To assess the process, approach, assumptions, and variables used in the O&M cost study for reasonableness.

The intent was not to check all the mathematical calculations included in the business plan, but to obtain an independent peer review of the overall O&M forecasts and of the individual cost components making up the total O&M estimates.

These forecasts were flanked to some current reference unit costs whose corresponding values are derived from HSR lines operating in France, Italy, and Spain.

It was not intended that an alternate O&M cost estimate be prepared, and no calculations were developed as part of the review. Rather, experts examined each major procedure and assumption used in building the overall O&M costs and then provided their comments (both favorable and constructively critical) regarding the techniques and assumptions employed.

2 COORDINATION AND COMMUNICATION WITH THE CHSRA PROJECT MANAGEMENT TEAM

Formal meetings between the experts and the CHSRA project management team were held under the supervision of UIC on the following dates for the indicative purposes:

Some preliminarily meetings and conference calls were established in order to evaluate and prepare the assessment on O&M

Date	Meeting/Conference call Purpose
September 24 to 28, 2012	To present the objectives of the review, the full description of the HSR project in terms of functionality, phasing schedule, ridership forecasts, operating plans, O&M cost calculations, and investment costs from the CHSRA project management team. To produce preliminary findings to the CHSRA project management team regarding data, assumptions, and procedures as detailed in this report at the end of this five-day seminar. This seminar was also attended by UIC representatives.
November 20, 2012	To answer detailed questions from the CHSRA project management team about infrastructure maintenance, energy consumption, and distribution mix. The experts' written responses are located in Appendix 1.

The CHSRA project management team cooperated with the independent review process. Requested information (describing data, HSR project overview methodology, model calibration, and sensitivity testing) were provided in a timely manner.

3 INFORMATION AVAILABLE FOR REVIEW

The following main reports were provided to the experts:

- *Estimating High-Speed Train Operating & Maintenance Cost for the CHSRA 2012 Business Plan*, prepared by Parsons Brinckerhoff for CHSRA, April 2012
- *California High-Speed Rail Corridor Statewide Improvements*, prepared by CHSRA, July 2012
- *2012 Business Plan Forecasts*, Final Report prepared by Parsons Brinckerhoff, June 2012
- *2012 Business Plan Update: Capital Cost Estimate Report,* prepared by Parsons Brinckerhoff for CHSRA, 2012
- *California High-Speed Rail Program*, Revised 2012 Business Plan, prepared by CHSRA, April 2012
- *Maps for Initial Construction Segment, Initial Operating Segment, Blended Service Overview*, CHSRA, September 2012
- *Concept of Operations*, prepared by CHSRA, February 2012

Other numerous reports prepared by the CHSRA, their program management team and other outside sources—regarding infrastructure, legislation, ridership forecasts, operations, infrastructure maintenance, rolling stock maintenance, RAMS, business plan—provided valuable information.

In addition to these documents, the CHSRA project management team provided the experts with data—such as information about detailed model components, sensitivity tests and detailed breakdown of demand forecasts—that facilitated the experts' work.

4 MAJOR REVIEW AREAS OF INVESTIGATION

The review process was organized to address four major areas of investigation.

4.1 The components of the O&M cost model

The aggregated cost categories of the model were reviewed for consistency and to ensure that all expected O&M costs incurred for an HSR line will be reflected into the model.

4.2 The calculation assumptions

O&M cost calculation requires assumptions about variables that are direct inputs into the process. Variables in this category include ridership forecasts, operating plans, productivity, and activity unit parameters. The assumptions used in producing the O&M costs were reviewed for reasonableness and consistency with one another.

4.3 The O&M model structure

The model structure developed by the CHSRA project management team incorporated both U.S. costs and the international ones provided as European references:

- The U.S. costs used in the model were either lump-sum costs (such as insurance) or variable costs (such as labor or energy costs) and clearly depended on the Californian context (U.S. labor legislation and practice, fiscal policy, burden rates on salary …). The U.S. costs were not part of the review because the experts thought that the CHSRA project management team was in a better position to define the U.S. inputs into the O&M cost model.
- Other costs regarding the maintenance activities of the HSR system were compared to the worldwide best current practices because there was no close analogy with the U.S HSR project.

4.4 The reasonableness tests

The O&M model cost calculations were evaluated by the experts for reasonableness on the basis of the assumptions made. This analysis did not include ridership projections, revenues, or service frequencies.

The O&M cost model's sensitivity to key input assumptions was provided by the CHSRA project management team and examined by the experts to determine if the model reacted to changes with respect of these variables in a manner consistent with observed current practices.

It should also be mentioned that the experts did not scrutinize the levels of rail service, the ridership volumes, and their related revenues as being input data whose analyses are not in the scope of this O&M costs review.

5 INDEPENDENT REVIEW FINDINGS

5.1 Uncertainties associated with O&M cost calculation

There is no single, universally accepted procedure based on HSR experience for forecasting O&M costs. Consequently, for a future HSR services in the U.S., this report can be based on the Experts' experience with these systems only in Europe.

Two different techniques were used in prior intercity travel studies and on this project: a top-down (or macro-economic) approach, using general benchmarks and providing global results, and a bottom-up (or micro-economic) approach based on unit costs applied to activity drivers. (The unit costs were based on U.S. values and compared to the analogous ones on other countries' experiences.)

Both techniques are recommended. Each of these techniques have proponents and critics, and it is difficult to definitively rate one as "better" or "worse". Therefore, the findings expressed in this report should be recognized as the opinions of the experts.

These opinions portray the experts' experiences with HSR O&M cost forecasting and with a generally conservative approach regarding the preparation of such calculations.

Such forecasting activity, by its very nature, includes a level of uncertainty. For example, assumptions about factors affecting overall travel demand, future wage rates, energy cost, etc. … may or may not actually happen.

O&M planners attempt to make reasonable assumptions in these areas using the "best" information available at the time the calculation was prepared.

However, it should be recognized that uncertainties still exist in the O&M cost process for three main reasons:

- The ridership forecasts and project cost estimates were studied for years and the O&M cost analysis is preliminary.
- The technology to be used has not yet been decided—especially in the areas of track systems and rolling stock—to meet the 220 mph performance measure.
- The current proven technology will evolve in a way that is difficult to predict.

5.2 Assessment of overall approach to O&M estimation

The experts concur with and endorse the following components of the conducted O&M cost calculation study:

- The definition of a detailed operating plan that provided activity drivers (train and trainset hours, train and trainset miles) to be used for O&M costs calculation.
- The breakdown of the O&M costs by category and unit
- The sensitivity tests of forecasts to different assumptions regarding key model input variables, including the passenger demand.

5.3 Presentation of O&M costs

The presentation of forecasted O&M costs, in the experts' opinions, implies a level of certainty (or at least does not fully explore the potential uncertainties), which could lead the reader to believe that these forecasted costs will almost certainly be achieved.

It is suggested that the CHSRA project management team's report would benefit by a prominently featured discussion of the uncertainties involved and, perhaps, of the clear identification of pessimistic and optimistic levels of O&M costs. An estimated range of O&M costs would be more accurate than a single number.

5.4 Assessment of O&M costs and procedures by major review area

5.4.1 The components of the O&M costs

The aggregated cost categories of the model were reviewed for consistency and to ensure that all expected O&M costs incurred for an HSR be included in the model.

The aggregated cost categories of the model and procedures appear to be well thought out, comprehensive, and consistent with the ridership demand and the operating plan.

However, some concerns were highlighted:

- A cost estimate for marketing and advertisement for this new mode of transportation should be added as a specific effort for implementing the project and during the 3 to 5

first years following its start-up by spending a percentage of the total annual revenues; this is consistent with the feedback of similar projects. When the market is mature, this spending may be reduced to 2 to 4% of the total revenues, depending on the competition context. **[Finding #1]**

- Annual variable costs based on the ridership volume should be considered for distribution and sales, depending on the expected distribution mix between the following sales' channels: internet, at-stations, call center and travel agencies. **[Finding #2]**
- In Europe, rail transportation tickets include sales taxes that have to be accounted for in O&M modeling. If similar services in California include sales taxes, then they should be added to the cost estimates. Sales tax has not been taken into account in the ridership and O&M cost modeling process.

  Should such sales taxes apply in California for this project, then the ridership forecasts should be revised as the modal choice should be based on the comparison of total travel costs (including sales tax) between the different transportation alternatives and O&M costs have to take into account the amount of sales tax to be paid as a percentage of the farebox revenues. (California has a base sales tax of 7.25%, and can total up to 9.75% with local sales tax included depending on the city in which the purchase is made). **[Finding #3]**
- It has also been noted that European commercial practice offers financial compensation to HSR travelers for major train delays.

  Regarding the California HSR system, standard run time was calculated by adding 7 percent on top of the computed pure run time. This padding accommodates schedule recovery due to random lateness, loss of adhesion due to weather conditions, and other delay types.

  Should the CHSRA decide to have such a commercial policy:

  - An additional recovery margin should be included in the standard run times.
  - Ridership forecasts should take into account this slight increase in travel time.
  - Financial provisions should be added on the O&M costs. **[Finding #4]**

5.4.2 The calculation assumptions

The experts reviewed and concurred with most of the assumptions used in forecasting the O&M costs. It should be noted that analyzing the project design and the ridership forecasts and evaluating their reasonableness were not in the scope of this review.

Ridership forecasts and project design have been considered as exogenous inputs. However, there are concerns about the following:

- The level of contingency to be applied to the O&M costs, which should be consistent with the level of contingency applied to the construction cost during this stage of design of the California HSR project. **[Finding #5]**
- The consistency between the operating plan and the ridership demand, which is a key aspect in developing O&M costs. The experts asked questions about the relationship between the demand seasonality and the operating plan.

  It was explained that the overall demand was broken down to an "average" hourly demand per day, and load factors were calculated accordingly and up to 100 percent for a peak-hour HSR train.

It is the experts' opinion that by using this methodology there is no certainty that the operating plan was sized to carry all the demand. For example, a train having a 100 percent load factor for an average Friday would not have enough capacity to carry all the demand for a peak-period Friday above the average Friday demand.

This procedure may lead to an understatement of the O&M costs or to an overstatement of the revenues. As a consequence, seasonality of the traffic should be analyzed in a more detailed breakdown, including the distribution pattern of ridership volumes at peak periods.

Further refinement of the operating plan should take into account this aspect; **[Finding #6]**

- The O&M cost escalation factor for the overall operation period should be linked to the expected escalation costs of labor, energy and raw material. The assumption made regarding labor cost should be in accordance with the income growth assumption used for the ridership forecasts. **[Finding #7]**
- A productivity factor should be part of the O&M calculation process since increased performance would be delivered over years, which should offset (partly or fully) the cost escalation. **[Finding #8]**
- Depending on the business model employed on the system, financial charges or leased costs should be added on whether the future operator purchases/leases the rolling stock and other assets. **[Finding #9]**

  O&M costs should be converted into O&M prices to reflect the "full" costs of the O&M activities.
- Depending on the business model employed on the system, the "franchisee" may not undertake all the technical tasks and may subcontract part of them. If such a business model is employed, the contractors in charge of O&M will receive a fee (or margin) to deliver the service and cover the technical risk. **[Finding #10]**
- A performance contract may be established between the CHSRA and the companies in charge of the O&M activities (based on a bonus/penalty contract), which would be an incentive to curb O&M costs. **[Finding #11]**

5.4.3 The O&M model structure

The experts reviewed the unit costs of the maintenance of the system (infrastructure and rolling stock) and accepted to provide reference values based on their European experience (as there is no possible analogy in the U.S.).

Infrastructure Maintenance

The experts agreed that the HSR infrastructure maintenance procedure and techniques are quite similar in the three countries they are originated from (France, Italy and Spain), resulting to a cost in the range of $190,000–$220,000[1] per route mile for a commercial speed up to 186 mph (300 km/h). The range of ±7 percent reflects potential differences in the design of the HSR (proportion of tunnels/bridges, slab or ballast track, etc.), the number of trains running the system, and local weather conditions.

[1] $2012 with the exchange rate of €1=$1.30

Translating this range of infrastructure maintenance reference values into the U.S. HSR project requires further expertise once the project design and the technology are fully determined.

The experts also recommend making a cost provision for speeds up to 220 mph (350 km/h). **[Finding #12]**

Appendix 2 provides more information about the European experience in the following fields: general policy of the infrastructure maintenance on an HSR line, undertaken issues between preventive and corrective infrastructure maintenance, maintenance of tunnels, and a detailed list of tools and equipment for maintenance infrastructure.

Rolling Stock Maintenance

The experts from France and Italy agreed that the HSR rolling stock maintenance procedure and techniques are quite similar in the two countries and result in a cost range of $9.40–$11.50[2] per trainset mile for commercial speeds up to 186 mph (300 km/h). The range of ±10 percent reflects potential differences in the design of the HSR rolling stock, the utilization of the trainset, and local weather conditions.

Translating this range of rolling stock maintenance reference values into the U.S. HSR project should require further expertise once the project design and the technology are fully determined.

This range of maintenance costs for HSR rolling stock does not take into account recent innovative maintenance procedures that may slightly reduce the overall cost of the maintenance.

The innovative philosophy, just being introduced for the maintenance of new, operating high-speed trains is called “condition-based maintenance”. This concept calls for a trainset sub-system monitoring system which is connected to a set of sensors distributed throughout the train. The sensors are designed to predict failure of component parts or sub-systems and allow for the performance of preventative maintenance in advance of actual failureThe remaining part of the subsystems will be done with a frequency related to the distance run by the train.

This innovative concept is being under testing, and it is still early to derive reliable costs of maintenance for rolling stock.

The experts also recommend making a significant cost provision for speeds up to 220 mph (350 km/h)) as preliminary findings show that the increase in equipment maintenance costs is above linearity when speed increases. **[Finding #13]**

Appendix 3 provides more information regarding the organization of the rolling stock and equipment in France and Italy. The appendix shows that these countries have set up similar procedures in the organization of the maintenance of the high-speed trains, resulting in comparable costs per train-mile.

[2] $2012 with the exchange rate of €1=$1.30

Electricity Consumption & Cost

The electricity consumption for trains running at 220 mph (350 km/h) has to be increased by 10 to 30 percent (depending on the topography of the HSR line) in comparison with trains running at 186 mph (300 km/h). **[Finding #14]**

5.4.4 The reasonableness tests

O&M cost model sensitivity to passengers' demand was examined to determine if the model reacts to changes in these variables in a manner consistent with observed current practices in Europe.

The model showed an elasticity of O&M costs to ridership levels of 0.6. This magnitude is considered too high and reflects a too-low proportion of fixed costs. **[Finding #15]**

Further enhancement of the model integrating the previous findings should fix this concern.

5.4.5 The optimization of the project

Some optimization in the design of the project may lead to significant decrease in O&M costs during the next enhancing phases of the project design:

- The review did not check the justification of the planned timetable but only the consistency between the assumptions taken in the ridership forecast modeling process and the O&M costs model. However, current practices in Europe have shown that a too systematic timetable and/or a desire to carry the whole demand during peak periods may lead to higher O&M costs. **[Finding #16]**
- The level of the ridership volume carried during the peak period compared to the level of demand carried during off-peak periods should be investigated in connection with a better knowledge of the ridership seasonality. Yield management techniques that are improving load factors during off-peak periods and increasing revenues during peak periods should be used. **[Finding #17]**
- It may not be optimized to have all trains running at 220 mph (350 km/h), particularly those trains with several intermediate stops. Very high speed is needed only for long-distances or when high-speed rail is competing with air. All OD pairs and market segments do not have air competitors. **[Finding #18]**

The design of the project at the speed of proven technology 220 mph (320 km/h) or at lower speed should also be assessed in terms of ridership forecasts, capital costs and O&M costs. **[Finding #19]**

6 CONCLUSIONS

The following summarizes findings from the independent eview:

- First, the experts have conducted their review, and no fatal flaws were found on the O&M cost process.
- Secondly, 19 findings have to be processed in order to assess their impact on the O&M cost order of magnitude.
- Finally, consistency between ridership forecasts, the operating plan, and the O&M cost evaluation should be more deeply analyzed.

A global project evaluation should be also performed for a project based on proven technology (meaning speed not exceeding 220 mph [320 km/h]) as a sensitivity case.

Appendix 1:

Questions raised by the CHSRA management team during the November 20th conference call

This appendix is listing the questions that have been asked by the CHSRA management team during the November 20th conference call and the answers provided by the experts.

1. Do track maintenance costs vary with level of usage (more specifically number of trains running over it, NOT trains of different weights)? If so, how?

The experts recommend using a fix cost per route mile in the preparation of the O&M cost model rather than a variable cost depending on usage for two main reasons:

- The level of usage of the foreseen California High-speed rail system is very similar to the one observed on the European high-speed rail lines, and the cost per route mile given at Finding # 12 is considered as appropriate for the California High-speed rail system under 300 kph speed;
- The track maintenance marginal cost is very low.

2. What is the length of track that a maintenance gang will cover? Is 110 miles reasonable?

European experience shows that a maintenance gang can cover from 50 km to 80 km in each direction and have a total length up to 100 km to 160 km in open country only.

3. What is the magnitude of cost differences between slab and ballasted track? Is the different in materials? In labor? In both?

Infrastructure maintenance experts consider that the extra cost for the construction of slab track is varying between +30% and +100% versus ballasted track. However maintenance cost is cheaper than the ballasted track.

4. What are the differences in maintenance needs/practices between conventional rail and HSR? Is the equipment different? Labor? Materials? Other?

There is no possible obvious comparison since the infrastructure maintenance best practices on existing lines focus on weak points of the network (where maintenance managers know that problems will occur) whereas the infrastructure maintenance on high-speed lines is systematic.

5. What are the cost differences in maintaining track in flat areas vs. in mountains or other difficult geographic/topological conditions?

It should be noted that, when infrastructure maintenance is concerned, special efforts have to be directed on the transition points of the high-speed line because they are requiring most of the corrective maintenance.

6. What is the number/volume of equipment that is needed? What types of vehicles?

A list of vehicles and equipment is proposed in Appendix 2

7. What proportion of overall infrastructure maintenance costs tends to be materials vs. labor vs. other costs? Are there significant differences between systems? If so, based on what?

Overall infrastructure maintenance costs are comprised of:

- 50% with labor costs;
- 25% with spare parts;
- 25% with other costs (such as tools, equipment, energy, management...).

8. How much energy do stations typically consume per square meter of space?

- For an open air station, the peak power is 30 W / m^2 and the energy consumption is 50 kWh/m^2 per year.
- For an underground station, the peak power is 90 W / m^2 and the energy consumption is 300 kWh/m^2 per year because of use of ventilation/air conditioning, elevators, and 24/24 lights

9. How much energy do maintenance facilities typically consume per square meter of space?

The energy consumption of the maintenance facilities is already included in the unit cost provided for rolling stock maintenance at Finding #13.

10. What are the distribution/ticket purchase percentages amongst different mechanisms?

As a highlight of how could be sold the tickets between different sales channel, an example of distribution mix for long-distance rail travels in Europe is as follows:

- 35% with internet (growing fast)
- 26% at stations (steadily decreasing)
- 2% with call-centers
- 22% with travel agencies
- 5% with vending machines (stable)
- 10% others

Appendix 2:
Infrastructure Maintenance Policy

This appendix is regarding maintenance of the infrastructure and is providing with more information about the European experience in the following fields:

- General policy of the infrastructure maintenance on high-speed rail line;
- Undertaken issues between preventive and corrective infrastructure maintenance;
- Maintenance for safety equipment in tunnels;
- Special considerations for the CHSRA infrastructure maintenance costs;
- Detailed list of tools & equipment for maintenance infrastructure on high-speed rail lines

A. General policy of the infrastructure maintenance on high-speed rail line

The Railroad Infrastructure Maintenance is divided into 2 packages:

Package 2a: Infrastructure Maintenance

- Structures;
- Earthworks, including permanent way, as well as depots, construction site and maintenance bases;
- Drainage;
- Fencing, portals, noise barriers; and
- Road accesses including corridor maintenance road.

Package 2b: System wide Maintenance

- Track work, including permanent right-of-way, as well as depots, construction site and maintenance bases;
- OCS;
- HV/LV Power Supply;
- Signaling & Operation Control Center (OCC);
- Control & Communication systems; and
- Electrical & Mechanical Equipment.

General Policy Statement

Infrastructure Maintenance is a very important activity and involves a wide variety of different assemblies, systems and components encountered over the whole length of the line. Maintenance consists of making sure that the line achieves its expected useful life, that traffic can operate in safety and that availability levels are high enough to offer good quality train paths, all at the lowest possible cost. This policy forms part of a continuous cost optimization and quality enhancement process.

Pre-operation Phase

Given the importance of maintenance in attaining the RAMS targets, a series of processes have to be developed from the earliest stage of the design phase, including the participation of maintenance experts in the following:

- Evaluation of maintenance costs and maintenance needs for all subsystems during the design phase;
- Safety case definition (maintenance part), in association with the construction team;
- General reference framework for Infrastructure Maintenance:
- Maintenance Policy Definition;
  - Maintenance Rules Definition;
  - Maintenance Manuals Definition;
- Follow-up to the workforce training, provided by the construction team;
- Workforce assessment;
- Handover process and works completion assessment;
- Final High Speed Line certification.

Maintenance Model

Maintenance management is under the responsibility of the O&M Company.

Its role is that of masterminding all actions designed to attain the targets and objectives set out for the project in terms of costs, quality, reliability, availability, maintainability, safety (RAMS), environment, etc.

The Maintenance Model to be used is based on proven and comprehensive High Speed experience.

Maintenance Policy

The O&M task is to maintain nominal line capacities, in terms of speed and throughput, at the lowest possible cost, and to schedule any necessary investment at the most appropriate moment during the life cycle of the line.

In the interest of maintaining railroad property assets, there are a number of basic guiding principles that the Maintainer must apply when making choices.

Work done on the various Railroad Infrastructure components must ensure the most effective and longest-lasting result.

The nature of a high speed line is such that more restrictive measures are necessary to maintain very high safety and regularity standards:

- As regards action taken in respect of any defects or faults; and
- In organizing maintenance operations.

Maintenance Policy consists of agreeing basic parameters (methods, program, budget, etc.), in relation to targets and objectives set each year. In order to optimize production costs, maintain safety levels for people and property, these parameters will, depending on the policy selected, give pride of place to:

- The life cycle of the equipment;
- Its availability;
- Quality of service; and
- Protection of the environment.

Maintenance policy will require choices to be made from among the following:

- Preventive and/or corrective, systematic or condition-based maintenance;
- Sub-contracting or own resources;
- Partial replacement of components or continued maintenance; and
- Scheduling the distribution of resources available for inspections and repairs.

Routine Maintenance Strategy

Routine maintenance management is based on exchanges of data acquired via the information system and various reporting procedures: production progress reports, cost and quality records compiled on the basis of the indicators requested, reports, minutes and recommendations regarding the consequences of the choices made.

Routine maintenance strategy, which is the result of maintenance policy, is synonymous with a number of choices that have to be made to attain or even better the targets set.

In such choices the emphasis is on:

- Constantly enhancing maintenance methods by keeping the reference documents up to date;
- Setting and improving maintenance cycles;
- Organizing the maintenance teams;
- Testing and approving the resources deployed by sub-contractors;
- Optimizing stocks of spare parts and consumables, ensuring that the inventory consists solely of the minimum necessary to maintain equipment close to the end of its useful life in operation;
- Allowing for the economic repercussions (ROI times) of modernizing or upgrading the tools used by maintainers with regard to productivity and maintainability criteria.

Routine maintenance strategy involves the use of a maintenance plan with clearly defined quantified targets and measurable indicators.

The results achieved in practice are set against the targets and are the subject of regular reporting.

A large part of the maintenance strategy concerns human resources, in other words staff within the company and those of outside firms:

- Selection & recruitment;
- Training;
- Skills and qualification management; and
- Communications.

Maintenance Levels

The normal five-level classification of maintenance levels generally used for industrial systems has been replaced by a simpler three-step version in line with normal practice based on experience in the high-speed operating sector.

In this accurate system, a distinction is made between:

- Step 1: simple maintenance operations (adjustment setting, replacement of consumables, lubrication, etc.);
- Step 2: maintenance of average to major complexity (repair or replacement of components, verifications, internal examination of equipment, inspections, etc.); and
- Step 3: major maintenance operations that correspond to Level 5 and are generally carried out by the manufacturer.

Maintenance Categories

There are three categories:

- Maintenance in situ: the operation is carried out on the particular piece of equipment where it is;
- Maintenance in the workshop: the equipment to be repaired is taken to a place on the site where the repair can be properly carried out; and
- Maintenance on the premises of the original manufacturer or a specialist firm: the equipment is taken away to a place that has the necessary facilities and where the necessary operations can be performed.

Maintenance Policy Development

Maintenance policy for railroad installations cannot be predetermined accurately and will have to be adapted to take account of changes in context. The requirements of the network owner, technological progress, analysis of feedback on practical experience, familiarity with the installations themselves or with given components are all factors that must be taken into account.

The only operations that may be deliberately sidelined are those clearly shown in each of the maintenance packages in of the specifications as depending on the decisions made as regards resource allocation.

Continual Improvement

While maintaining the same safety levels, any new maintenance developments should enable the following objectives to be met:

- Allowance for audit findings;
- Adaptation of costs to the service level required on any given section of line;
- Right choice between preventive and corrective maintenance in order to better take into consideration the potential impact of equipment failure in relation to factors such as line safety/regularity/comfort;
- Improvement in the status of railroad assets. The availability of standards for most of the specialties simplifies the task of deciding whether to replace a component or to adjust its settings. This objective is essentially dependent on being fully familiar with the infrastructure assets and can also be the result of making better allowance for the real causes of component deterioration: age, speed, loads and stresses, etc.;
- Greater economic efficiency. This objective may be attained by making conscientious use of information gleaned from feedback and from keeping better records of past operations. For example, by replacing electronic signaling components or parts of the OCS system as a preventive measure, it is possible to drive down overall maintenance costs. In addition, the nature of the operations to be performed also offers margins for

improvement; for example: preventive rail grinding is one way of lessening the number of track defects and contact fatigue encountered and will ultimately enable the number of rail replacements to be reduced;

- Methodical exploitation of on-board measurement data helps to cut the number of inspections and ensure intervention at the right place and the right time thanks to the repetitive nature of the measurements that show up any progression of incipient defects;
- Improving staff working conditions. The advent of new standards is important where worker protection is concerned, so companies tend constantly to develop and adapt their tools to make work less arduous: elevator platforms, transport and inspection vehicles, mechanized solutions, automatic warning systems (lookouts), etc.; and
- Introduction of enhancements of all kinds (maintenance plans, technical modifications, etc.) should provide all the guarantees necessary that any expected savings will not just be theoretical but will culminate in greater reliability and thereby in measurable cost reductions reflected in the organization.

Predictive / Preventive Maintenance

- Systematic Preventive Maintenance

  Systematic preventive maintenance includes the maintenance operations required by the law or by the regulatory requirements. It also includes formal planning, clear and accurate descriptions of the work to be done (cleaning, lubrication, replacement of parts, etc.) and keeping a record of the work done (traceability) by means of standard systems enabling the information acquired to be fed up the line and analyzed.

  Systematic preventive maintenance is applicable in relation to wear phenomena that follow generally known patterns (number of trains or shunting movements, etc.).

  It is for this reason that this type of maintenance does not require any prior examination of the state of the installations concerned. Such maintenance can be carried out at particular periods of the year (weather conditions: opening of joints and expansion devices, etc.)

- Condition-based Preventive Maintenance

  To make greater allowance for the true state of wear of the equipment in cases where a pre-determined threshold is exceeded (wear, temperature, etc.) or where the maintenance operative spots a visible change of condition (noise, visible anomaly, etc.), it is possible to readjust settings or replace the affected parts.

  Remote monitoring based on continuous measurement of parameters indicative of the degree of deterioration in any particular piece of equipment can, in some cases, constitute major progress by enabling costly, unjustified, repetitive tasks to be changed or even discontinued.

- Predictive Preventive Maintenance

  By analyzing the progression of significant wear factors it is possible to schedule the appropriate action.

  Condition-based or predictive preventive maintenance represents progress by comparison with preventive maintenance based on objective measurements of the parameters intervening in the deterioration of components, assemblies, etc. It is based on the principle of extrapolating values and producing trend graphs in relation to different rates of use of the particular equipment.

Graphs are produced from the successive measurements recorded set against data received from feedback. The efficiency of the system is ensured by a three-stage process which consists of periodical or continuous measurements, processing of the resulting data and diagnostic analyses to enable the corresponding operations to be scheduled.

- Operations based on accepted working methods

  To ensure that all operations are performed to the same high standards of quality and safety, maintenance staff has reference documents at their disposal as well as maintenance instructions outlining the purpose of the operation and the procedures and resources to be deployed. These reference documents and manuals form part of the maintenance documentation.

Monitoring

By organizing preventive maintenance there can be no complete certainty that a failure will not occur between two scheduled inspections. Such failures may be the result of outside causes (storms, willful damage, etc.) or of misjudged estimation of the degree of criticality (problem developing more rapidly than expected).

To spot such defects, it is therefore necessary to organize systematic inspection of certain installations. These inspections may be conducted on foot or on trains using on-board measuring equipment to reduce the amount of human intervention and enable the most appropriate moment for action to be selected thanks to frequent repetition of the measuring process.

Corrective Maintenance

Corrective maintenance consists of repairing equipment at least temporarily and/or in part so that it can continue to perform its intended function.

It includes, in particular:

- Fault diagnosis (detection, location, analysis);
- Immediate corrective or palliative action (full functioning required or downgraded operation);
- Deferred corrective action with or without improvement; and
- Function tests.

Corrective maintenance is not necessarily less expensive since it is not scheduled and requires substantial resources, in particular in terms of out-of-hours personnel.

Maintenance Engineering

Maintenance engineering consists of:

- Establishing maintenance policy, strategy and plans;
- Optimizing maintenance;
- Specifications, reference documents and development of support system components;
- Monitoring actual maintenance operations via the indicators in the records (log); and
- Application of the MOC principle (Maintaining in Operating Condition) to the products and systems in order to spot incipient obsolescence and propose the necessary measures in good time to the network owner.

It consists of analyzing maintenance requirements, feedback, stock consumption, proposing improvements to installations, submitting the documents in support of the investment case for renewal projects, where necessary, throughout the duration of the concession.

Choice of equipment used for maintenance

In view of procurement lead times and the purchase price of the equipment needed, it is necessary to keep stocks to limit the repercussions of failures, especially in terms of availability. The list of parts to be kept in store is drawn up, allowing in particular for:

- The operating and reliability conditions specific to the equipment to be maintained which also affect the consumption of such articles;
- The frequency of systematic replacements;
- Expected consumption for a specific period;
- Procurement lead times, which may interfere with the availability of the equipment (indirect costs);
- Acquisition costs (purchase price, transport, etc.);
- Ownership costs (financial costs, storage costs, etc.); and
- Storage conditions (shelf life).

These operations can be conducted on the basis of the preventive maintenance plan, analysis of feedback and the manufacturer's recommendations. The number of articles to be kept in stock is calculated in relation to the number of original components and repeat purchase thresholds are set in relation to the risk of stock outages.

Maintenance stocks fall into five categories:

- Consumables;
- Parts scheduled for replacement;
- Parts not scheduled for replacement;
- Parts exceptionally replaced; and
- Equipment and tools used exclusively for maintenance: the various tools and devices needed to perform maintenance operations.

These tools can be placed in two categories:

- Small tools (hand tools or portable measuring devices) at the disposal of the operatives; and
- Large tools, track and other recording vehicles employed on a scheduled basis.

Maintenance Operations

The conditions necessary for performing the maintenance operations set out within the strategy need to be the subject of constant consideration at all levels of the company: the methods, tools, vehicles and equipment used and the conditions governing the different operations are all vital factors in achieving top-notch maintenance standards.

This extends, in particular, to the planning of the different activities, which must be described in detail at basic task level and include coordination among all the various players. The planning process also needs follow up and control:

- To ensure the availability of the material and logistics resources necessary (spare parts, tools, etc.);
- To coordinate operations;
- To manage unexpected events requiring immediate response;
- To contribute towards optimizing maintenance costs in order to reduce overall costs; and
- To ensure that the proper information is stored and circulated.

All technical or safety checks conducted in accordance with the conditions set out should be performed during the implementation phase and/or before the system is placed back in service, by authorized individuals with clearly defined responsibilities. But this shall in no way preclude the need for individual workers or gangs to check their own work as they go along.

Interfaces

- Internal interfaces between Construction and Operating during project phase

  During the Design and Construction phase, a maintenance director, maintenance engineers, system integration experts for each railroad system discipline (Track, OCS, Signaling, Telecommunications and Power Supply) will be appointed to review and comment on maintainability. During the design phase they will work with construction staff to ensure the system being constructed can be readily maintained. Infrastructure reference framework and organization will be designed by a team in charge of maintenance system design.
- All technical activity interfaces

  A railroad organization must manage many interfaces to ensure optimum performance. Any Barriers between the operator and the various maintenance disciplines must be as indiscernible as possible.

The O&M Company will endeavor to encourage mutual understanding of each organization's needs throughout the maintenance period. This will be achieved by locating staff at similar levels close to each other and, where practical, in the same locations so that they can freely communicate and understand each other's opinions. This may extend to joint social activities to further improve communications.

B. Undertaken issues between preventive and corrective infrastructure maintenance

The maintenance policy is the set of technical and organizational actions and strategies required to achieve the maintenance objectives. Whereas the rail transport system is a complex system involving different techniques and technologies (civil, mechanical, electrical, electronic and telecommunications), it's often necessary to diversify the maintenance policies according to the technical characteristics, especially regarding the mix between preventive and corrective maintenance.

The table below indicatively shows the relevance of the different types of maintenance for the main subsystems of the rail infrastructure.

Subsystem	Preventive	Corrective
Civil Works (*)	High	Low
Railway track	High	Low
Contact Line	High	Low
Power Supply	Low	High
Signaling & TLC	Low	High

(*)Including the superstructure, excluding the railway track

The table shows that Civil Works maintenance is based exclusively on the preventive maintenance, while for Signaling and Telecommunications the maintenance is almost exclusively of corrective type.

To achieve the cost-effectiveness objectives the maintenance should be organized for the various subsystems in order to modulate operations according to the real needs, as following:

- Preventive maintenance policies should be oriented to on condition maintenance activities;
- Redundant criteria of the electronic subsystems project have to be observed in order to assure maintenance corrective activities without operational line consequence.

In order to make these tools effective it is necessary to carry out a constant monitoring of the effectiveness of the maintenance with the analysis of the deviations from the objectives and the design of the related corrective actions (both of a technical and organizational type).

Maintenance Types

Civil Work

The maintenance of civil works concerns essentially the cleaning works (this is particularly important for drainage networks), the surveillance controls and inspections carried out along the railway line to verify the status of the structures, and eventually monitoring of “On Condition” maintenance interventions.

The Corrective maintenance is not programmable, even if the “On Condition” and the characteristics of the Civil Works make the need of a real corrective action extremely unlikely.

Railway Track

The suitability of the track subsystem assumes a value of reliability that is highly dependent on the preventive maintenance Reliability is not only relevant for the operation but also for the safety of the train’s running.

The approach to the preventive maintenance for tracks (including fastenings, railway sleepers, ballast , etc.) is an approach of “On Condition” type that implies the determination of conditions (geometrical and mechanical), thorough the measurement of parameters, that provide the indications for the need of actions in order to guarantee perfect working conditions. All maintenance actions on the track require the out of service of the track or slowdown in the adjacent track.

Electric traction and power supply

Overhead line

The operation “availability” degree is related to the preventive maintenance, consisting mainly of inspections in preparation for the “on condition” maintenance and to measurements with diagnostic trains that allow maintaining a high reliability of the subsystem. The preventive maintenance concerns essentially the mechanical and geometrical properties of the subsystem.

The availability of supply systems of the overhead line (electric traction substation) is related with preventive maintenance (cyclic) operations that include essentially visual inspections of the equipment (status of the connections, etc.), and maintenance operations to assure the efficiency of some critical components such as transformers (for example oil and salt control) or breakers and switches.

Usually the redundancy of the system allows the execution of preventive and corrective maintenance actions without disturbance to the railway operation.

Power Supply Remote Control System

The electric traction remote control system is essentially composed of electronic components so preventive maintenance operations are extremely limited and have little effect on the subsystem reliability. However, the reliability is evaluated with periodic tests, performed remotely, to verify the correct operation.

Signaling and telecommunication

System components are essentially electronic, so preventive maintenance is extremely limited and does not have a significant impact on the reliability. However, it is appropriate to provide the possibility of conducting periodic tests on the subsystem.

The objectives of availability to the operation can be achieved by redundancy with an electronic and/or electro-mechanic system that is fully redundant in both hardware and software, and is concentrated in the Control centers, so it is often possible to have interventions in corrective maintenance not affecting the railway operation.

To achieve the availability goal the non-redundant components, like switches and track circuits, preventive maintenance includes test cycles performed daily.

Main Maintenance Activities

Systems for which preventive maintenance is relevant, the maintenance policy is “On Condition” approach based: after inspection, if “conditions” are matched, you can schedule the corrective action.

Following are listed the main infrastructures inspection activities, that are forecasted by High Speed with related frequency.

Infrastructure System	Type of inspection	Daily	Weekly	Monthly	90 Day
Basic Track	Vehicle Track Interaction	**X**			
	Gage Restraint	**X**			
	Visual inspection		**X**		
	Control of the geometric parameters: gauge, horizontal alignment geometry, vertical alignment geometry, switch point geometry and railway switchgear, cross-sectional level, twist, rail wear, verification of rail defects with accelerometer measures		**X**		
	Recognition of the state of the rail track with walking inspection (joints, fasteners, etc.)			**X**	
	Nondestructive control (ultrasonic)				**X**
Basic Catenary	Measurement of the distance, of the thickness of the contact line and its			**X**	
	Review of the contact line, in correspondence of the rail switches			**X**	
	Cleaning fixed equipment of electric traction				**X**
	Visual inspection of places of voltage change isolation and of phase change.			**X**	
Basic Struct.	Visual inspection of bridges, tunnels, culverts, etc.			**X**	
	Monitoring the stress state of the tunnels				**X**
	Checking and eventual cleaning of the water drainage system				**X**
Basic Signal	Check and Cleaning signals, Panels, sensors …			**X**	
	Equipment controls: physical status and isolation measures the electrical circuits			**X**	
	Checking the conditions of the control and of the protection commands			**X**	
	Switching Test	**v**			
	Switching checking			**X**	

C. Maintenance for safety equipment in tunnels

The aim of this section is to summarize the state of the art in terms of tunnel safety installations maintenance procedure and cost in the Spanish high-speed network.

DESCRIPTION OF MAINTENANCE

The maintenance of tunnel safety installations depends on the tunnel category and, therefore, the number of related installations.

Consistent with the UE technical specification of interoperability (TSI) relating to 'safety in railway tunnels' in the trans-European conventional and high-speed rail system, there are established two categories of tunnels, for which the related installations are defined (plus specific cases addressed particularly):

- tunnels of less than 1,000 m in length
- tunnels of more than 1,000 m in length

INSTALLATIONS PER TYPE OF TUNNEL

Tunnels of less than 1,000 m in length

Safety installations in these tunnels are the following:

- Safety installations:
  - Escape signage
- Security Installations
  - Safety installations monitoring and control
  - Perimeter security systems

Tunnels of more than 1,000 m in length

Safety installations in these tunnels are the following:

- Safety installations:
  - Ventilation of emergency exits and technical rooms
  - Fire detection and extinguishing systems in emergency exits and technical rooms
  - Fire extinguishing systems in tunnel
  - Evacuation doors
  - Escape signage
  - Gas detection systems in tunnel
  - Radio communication system
  - Electrical outlets in technical rooms and lobbies
- Security installations
  - Safety installations monitoring and control
  - Perimeter security systems

Other security and safety installations (lighting, intrusion and access control, CCTV, etc.), and their maintenance may be integrated into energy and telecommunications systems.

MAINTENANCE PLAN

The main objective of Maintenance is to keep all the high-speed line systems and equipment in a perfect state of conservation and functionality, ensuring both their safety and reliability.

Thus, it is necessary to inspect the installation status periodically by anomaly detection methods and comparison with nominal status.

In case of discrepancies affecting service availability or people/equipment safety, installation shall be repaired immediately.

Analysis is based both on the installation status but also on its evolution, comparing it with the standards. This allows to forecast the future evolution of the installation and to make corrections before any issues arise.

Maintenance staff must be trained and equipped to develop any related work and to repair unpredicted failures.

Contracts for tunnel safety installations design in high-speed lines cover the following types of maintenance:

Preventive maintenance	Corrective maintenance
Cyclical	Scheduled
According to status	Not scheduled
Predictive	

MAINTENANCE COSTS FOR SAFETY INSTALLATIONS IN TUNNELS

Investment costs for tunnel safety installations execution are significantly linear in 'short' tunnels (up to 5,000 m) but they soar in 'long' tunnels (more than 5,000 m in length).

According to recent contracts, the average tendering amount for safety installations annual maintenance fits in a range between 2.5% and 7.5% of the total investment for the installations execution, depending on the type of tunnels covered by the contract and maintenance characteristics.

The section between Ourense and Santiago may serve as an example of a contract put out to tender recently in the Spanish High Speed Railway Network. The tender process (2011) included safety installations execution in tunnels and maintenance during the first three years of operation, with the following numbers:

- Number of tunnels: 30
- Total length of tunnels: 28,834 m (Length range between 160 – 2,866 m)
- Tendering amount for installations execution: 28,224,924 € (tax not included)
- Tendering amount for installations three-year maintenance: 4,032,209 € (tax not included).

Therefore, the tendering amount for the annual maintenance during the first three years, 1,344,069 € (tax not included), was equivalent to a 4.76% of the foreseen investment for the execution, and the extra cost for maintenance for safety installations in tunnels is about €47,000 per km of double track.

D. *Special considerations for the California HSR infrastructure maintenance costs*

Italian High-speed rail line characteristics

The following table resumes all the sections of the Italian high-speed rail network and for each of them indicates the length and percentage of the different types of civil works.

	TO-MI	*MI-BO*	*BO-FI*	*FI - RO*	*RO-NA*	*BO*		
	Miles	**Miles**	**Miles**	**Miles**	**Miles**	**Miles**	***TOT*** ***Miles***	***TOT*** ***%***
CUTTINGS AND ENBANK.	**60,5**	**85,9**	**2,4**	**83,8**	**87,7**	**1,8**	**322,1**	**59%**
BRIDGES AND VIADUCTS	**17,1**	**27,9**	**0,7**	**26,0**	**25,4**	**0,2**	**97,4**	**18%**
TUNNELS	**0,6**	**2,4**	**47,7**	**47,3**	**21,4**	**7,3**	**126,8**	**23%**
TOTAL	**78,3**	**116,2**	**50,8**	**157,1**	**134,5**	**9,4**	**546,3**	**100%**

It's clear from the last column of the table that the percentage of tunnel in Italian high-speed rail network is huge due to the orographic condition of the Italian territory. This situation probably increases the maintenance cost of infrastructure in Italy.

Speed of 300 kph versus 350 kph

The 60/70% of maintenance operations is referred on track and catenary that are speed sensitive.

The impact assessment of speed on catenary and overhead line is a simple forecast of friction consumption which is in direct proportion with speed level; the "theorical" increase of maintenance corrective actions should be at least 20% (based on extrapolation from available information).

For the on ballast track, in addition to the friction consumption effect, there are the rolling stock transverse forces applied to the track which are proportional to the square of speed. The "theorical" increase of the maintenance activity on the geometry of the track should be at least 40% (based on extrapolation from available information).

Conclusion

The comparison between the Italian maintenance cost value and the CHSRA one has to take into account:

- The maintenance activities foreseen by CHSRA that are very similar to the European ones (with the only exception of the CMIV daily inspection not performed in Italy);
- The maintenance activities foreseen by CHSRA that should be evaluated at 350 km/h;
- The maintenance cost for the Italian network that is calculated with an operational speed of 300 km/h;
- The special characteristic of the Italian network with a huge percentage of tunnels) to be compared to the California High-speed rail project.

E. Detailed list of recommended infrastructure maintenance vehicles/equipment

Examples of Vehicles, tools and equipment used for infrastructure maintenance on the French high-speed rail lines to maintain about 250 miles of track:

ACTIVITY	VEHICLES / TOOLS	QUANTITY
Track	Hybrid tamper (not dynamic)	2
	Tamper type 109 or 09	1
	Emv 98 (multi-function vehicle with rail straightener)	2
	Grinder 24 heads (hybrid) (plain track + switches)	1
	Ultrasonic Rail Control Train	1
	Rail motor car	2
	Stabilizer	2
	Ballast regulator stab	2
	PMC (frog handling gantry) Set of 2 gantries	1
	Inspection Vehicle (Truck included)	4
	Locomotives (5 dedicated to Maintenance, 4 for rescue purposes)	9
	50T ballast hoppers	40
	Flat freight cars	12
	R40 flat freight cars (emergency fleet Baker)	3
	Flat freight cars R66 (emergency fleet Baker)	2
	Track/OCS geometry Measuring Train	1
	Grasshopper (ballast loader)	2
	Rail-road shovel unit (with hydraulics)	4
	Ballast cleaner/screener with switch cleaning option	1
	Self-discharging freight cars	6
Civil Works	Inspection platform for Bridges (freight car)	1
		3
OCS	Dynamic Track Acceleration and OCS Measure	
	Self-propelled OCS unit	4
	OCS maintenance motorcar	2
	OCS wire installation (for short length intervention)	1

In addition, specific tooling is required for each subsystem. The following examples are not exhaustive but are representative of the sort of equipment that is needed.

EXAMPLES OF NEEDED MAINTENANCE EQUIPMENT FOR TRACK

Super light saw
Super light rail drill
Trimming machine
Mechanical grinding unit
Hydraulic jacks
Tamping jacks
LWR clamps
Socket T – wrench
Adjusting devices
Points locking bolts
Rail lifting jacks
Measuring and gauging instruments
Hand-pushed sticks and rail carts for Ultrasonic rail inspection
Laser surveying recorder
Rail head wear measuring instruments
Portable coach screwing machine
Abrasive rail saw
Hydraulic rail shears
Hydraulic rail tensors
Rail knocker
Carts
Vertical joint straightener
Railroad loaders
Portable vibrating ballast tamping
Gantry cranes
Lightweight rail carts
Self-propelled rail carts
Acoustic warning devices
Lightning generator sets
Etc…

EXAMPLES OF NEEDED MAINTENANCE EQUIPMENT FOR OCS

Wire splicing device
Insulator remover
Cantilever unit
Tirfor cable
Wire cleaning brush
Heating, cutting, welding torch
Hydraulic shears
Holding valve
Torque wrench, digital dynamometer, 5-ton dynamometer
Ladders
Slings and threaded ends
Acetylene brazing/welding kit, arc welding unit
Cantilever insulator changing tool
Generator unit, hydraulic power unit
Die sets
Lugs 1,000 Kg, 1,500 Kg
Clamps UPK 93, UPK 288
Rail foot clamp
Crimping clamp
Adjustable telescopic poles
Catenary vehicle pole (with/without extension)
Digital sliding calliper
Tecalimit pump
Set of pulleys
Hydraulic press
Pull lift 1,500Kg; Pull lift 3,000 Kg; Pull lift 750 Kg
Laser gauge
Earth tester (KOC)
Hydraulic jack
Dropper claw setting and removing tool
Switch rod head
Hydraulic kink remover
Tensile test bench (droppers)
Tractel tensiometer
Electric lubrication pump
Overhead line inspection camera, thermal cameras
Etc…

Appendix 3
Rolling Stock Maintenance Policy

This appendix is regarding maintenance of the rolling stock and equipment and is providing with more information regarding:

- General policy & organization of maintenance of the rolling stock & equipment
- Details about the three first intervention levels

It shows that the two countries (France and Italy) have set up similar procedures in the organization of the maintenance of the high-speed trains resulting in comparable costs per train-mile.

A. General policy & organization of maintenance of the rolling stock & equipment

Rolling Stock maintenance is a key element in any operation, since it must not only meet all safety requirements but also be given due consideration in relations with the Operators,

The keys to success are as follows:

- The ability to develop a maintenance system that optimizes fleet availability;
- The ability to develop a maintenance regime that delivers a high level of fleet reliability at an acceptable cost;
- The ability to develop a maintenance system that can be integrated into the train running diagrams;
- Maintaining very high safety levels,

Maintenance consists of:

- Vehicle maintenance;
- Technical work to improve both the maintenance regime and the maintenance documents;
- Repair of spare parts,

Given the importance of maintenance in attaining the RAMS targets, a series of processes have to be developed and a series of standards finalized, These documents constitute the general reference framework for Rolling Stock Maintenance,

Maintenance Management

Maintenance management is under the responsibility of the company in charge of performing the maintenance operations,

Its role is that of masterminding all steps taken to attain the targets and objectives set out by the network owner in terms of costs, quality, reliability, availability, maintainability, safety (RAMS), environment, etc.,

Routine maintenance management is based on exchanges of information between the various entities going to make up O&M, on the one hand, and the rolling stock supplier, on the other, Information is acquired via the information system and various reporting channels:

production progress reports, cost and quality records compiled on the basis of the indicators requested, reports, minutes and recommendations regarding the consequences of the choices made,

Maintenance Policy

The O&M's task is to operate the business (trains, compliance with punctuality requirements, delivering a high level of safety and comfort),

In the interest of maintaining railway property assets, there are a number of basic guiding principles that the Maintainer must apply when making choices,

Maintenance Policy consists of agreeing basic parameters (methods, program, budget, etc.,), in relation to targets and objectives set each year by the network owner, In order to optimize production costs, maintain safety levels for people and property, these parameters will give pride of place, depending on the policy selected, to:

- the life cycle of the equipment;
- its availability;
- quality of service;
- protection of the environment;
- etc.,

Maintenance policy will require choices to be made from among the following:

- preventive and/or corrective, systematic or condition-based maintenance;
- sub-contracting or own resources;
- partial replacement of components or continued maintenance; and
- scheduling the distribution of resources available for inspections and repairs,

Routine Maintenance Strategy

Routine maintenance strategy, which is the result of maintenance policy, is synonymous with a number of choices that have to be made to attain or even better the targets set,

In such choices the emphasis is on:

- constantly enhancing maintenance methods by keeping the reference documents up to date;
- setting and improving maintenance cycles;
- organizing the maintenance teams;
- testing and approving the resources deployed by sub-contractors;
- optimizing stocks of spare parts and consumables, ensuring that the inventory consists solely of the minimum necessary to maintain in operation any equipment that is close to the end of its useful life;
- allowing for the economic repercussions (ROI times) of modernizing or upgrading the tools used by maintainers with regard to productivity and maintainability criteria,

Routine maintenance strategy involves the use of a maintenance plan with clearly defined quantified targets and measurable indicators,

The results achieved in practice are set against the targets and are the subject of regular reporting,

A large part of the maintenance strategy concerns human resources, in other words staff within the company and those of outside firms:

- selection & recruitment;
- training;
- skills and qualification management;
- communications;
- etc.,

Maintenance Levels

The normal five-level classification of maintenance levels generally used for industrial systems has been replaced by a simpler three-step version in line with normal practice based on experience in the high-speed operating sector,

In this highly precise system, a distinction is made between:

- Level 1: basic service performed in the course of revenue service (daily checks performed by the driver during train preparations, for instance**)**;
- Level 2: Checks, Maintenance operations on dedicated installations, In service examinations, fault-finding and fixing, cleaning, Performed by RS maintenance staff**,**
- Level 3: Periodical inspections**:** Performed by RS maintenance staff, Vehicles have to be withdrawn from revenue service,
- Level 4: Major overhaul,
- Level 5: Modernization, refurbishment, major repairs,

Maintenance Categories

There are three categories:

- maintenance in situ: the operation is carried out on the particular piece of equipment where it is;
- maintenance in the workshop: the equipment to be repaired is taken to a place on the site where the repair can be properly carried out; and
- maintenance on the premises of the original manufacturer or a specialist firm: the equipment is taken to a place that has the necessary facilities and where the necessary operations can be performed,

Preventive Maintenance

- Systematic Preventive Maintenance

  Systematic preventive maintenance includes the maintenance operations required by law or by the regulations, It also includes formal planning, clear and accurate descriptions of the work to be done and keeping a record of the work done (traceability) by means of standard systems enabling the information acquired to be fed up the line and analyzed,

  Systematic preventive maintenance is applicable in relation to wear phenomena that follow generally known patterns (mileage and time),

That is why with this type of maintenance there is no need for prior examination of the rolling stock concerned,

- Condition-based Preventive Maintenance

  To make greater allowance for the true state of wear of the equipment in cases where a pre-determined threshold is exceeded or where the maintenance operative spots a visible change of condition, it is possible to readjust settings or replace the affected parts,

- Predictive Preventive Maintenance

  By analyzing the progression of significant wear factors it is possible to schedule the appropriate action,

Condition-based or predictive preventive maintenance represents progress by comparison with preventive maintenance based on objective measurements of the parameters involved in the deterioration of components, assemblies, etc., It is based on the principle of extrapolating values and producing trend graphs in relation to different rates of use of the particular equipment,

Corrective Maintenance

Corrective maintenance consists of repairing equipment at least temporarily and/or in part so that it can continue to perform its intended function,

It includes, in particular:

- fault diagnosis;
- immediate corrective or palliative action (full functioning required or downgraded operation);
- deferred corrective action with or without improvement; and
- function tests,

Corrective maintenance is not necessarily less expensive since it is not scheduled and requires substantial resources, in particular in terms of out-of-hours personnel,

Continual Improvement

While maintaining the same safety levels, any new maintenance developments should enable the following objectives to be met:

- Allowance for audit findings;
- Adaptation of costs to the service level required on any given section of line;
- Right choice between preventive and corrective maintenance in order to make better allowance for the potential impact of equipment failure in relation to factors such as line safety/regularity/comfort;
- Improvement in the status of company assets, The availability of standards for most of the specialties simplifies the task of deciding whether to replace a component or to adjust its settings, This objective is essentially dependent on being fully familiar with the rolling stock assets and can also be the result of making better allowance for the real causes of component deterioration,
- Greater economic efficiency, This objective may be attained by making conscientious use of information gleaned from feedback and from keeping better records of past operations,
- Improving staff working conditions,

- Introduction of enhancements of all kinds (maintenance plans, technical modifications, etc.,) should provide all the guarantees needed to ensure that any expected savings will not just be theoretical but will culminate in greater reliability and thereby in measurable cost reductions reflected in the organization,

Maintenance Engineering

Maintenance engineering consists of:

- Establishing maintenance policy, strategy and plans;
- Optimizing maintenance;
- Specifications, reference documents and development of support system components;
- Monitoring actual maintenance operations via the indicators in the records (log); and
- Analyzing maintenance requirements, feedback, inventory consumption, proposing improvements to installations, submitting the documents in support of the investment case for technical modifications, where necessary, throughout the life of the fleet,

Depot specifications

Workshops:

Experience has shown the need for dedicated workshops to support operations. Either side of the Bogie Drop building is two workshops, both fitted with 10 ton overhead cranes:

- Heavy Electrical Repairs Workshop (Common Bloc, Motor Bloc etc.,); and
- Bogie Overhaul Workshop

Servicing/Maintenance Building:

All roads should be fitted with a sunken floor/raised rail arrangement. The sunken floor runs the complete length of the train thus removing the need for nose access platforms to be specially shaped to the ramp profile,

Underside inspection pits with inspection lighting run the length of the train. All roads should be fitted with overhead catenaries energized at 25kV AC along their length,

Electrical and air supplies should be provided for each vehicle and fitted to rail support posts, Specific supplies for battery chargers and shore supplies should be provided at those vehicle positions where such equipment is found, Hot and cold water supplies for cleaning purposes should be provided at intermediate points along the roads,

Overhead cranes with a 2.5 ton lift capability each serving pairs of roads should be installed, Retractable catenaries should be located below the working height of the cranes,

Bogie Drop/Wheel Lathe Building:

Experience has shown how crucial these facilities are to supporting operations, The bogie drop arrangement should offer sufficient capacity to minimize the need for trains to wait for their bogies to be removed, This could be achieved by an arrangement that serves two working roads, thereby allowing two trains to be worked on simultaneously,

Maintenance Operations

The conditions necessary for performing the maintenance operations required by the maintenance strategy need to be constantly under review at all levels within the company:

the methods, tools and equipment used and the conditions governing the different operations are all vital factors in achieving top-notch maintenance standards,

This applies, in particular, to the planning of the different activities, which must be described in detail at basic task level and include coordination among all the various players. The planning process also needs to be supervised and monitored:

- to ensure the availability of the material and logistics resources necessary (spare parts, tools, etc.,);
- to coordinate operations;
- to manage unexpected events requiring an immediate reaction;
- to contribute towards optimizing maintenance costs as a means of keeping down overall costs; and
- to ensure that the proper information is stored and spread,

Close relations between Operations and Maintenance are necessary to ensure that maintenance issues are addressed to the greatest possible extent as an integral part of operations.

B. Details about the three first intervention levels

The organization of maintenance of the high speed rolling stock fleet can be summarized into three different intervention levels, each of which is connected to specific maintenance tasks and required equipment.

Maintenance Depot Workshops can be set at the same locations as Depots for train crew and drivers, but they can also be set in different locations. Only Depot Workshops are treated in this paragraph.

The different levels of maintenance and the related main maintenance tasks can be described as follows:

- Level 0 - Servicing
- Level 1 - Depot Workshop Service and Maintenance
- Level 2 - Main Workshop Maintenance

As said, each of them requires different resources in terms of:

- Organization
- Skilled staff
- Spare parts
- Tools
- Infrastructure facilities and equipment

Main characteristics of the three levels of maintenance are described in the following paragraphs.

Level 0 - Servicing (Stations area)

Level 0 servicing operations are normally carried out at each end of train routes.

The operations can be carried out in station tracks on train arrival or before leaving, depending on service needs.

For Level 0 operation one or two technical operators are required. These operators must be qualified for routine checks and controls and for minor repairs.

A small store for spare parts and consumables (i.e. lamps, relays, filters, etc...) and a kit of transportable tools are required for minor maintenance operations.

Cleaning and on board servicing are not part of technical staff scope of works, but are normally carried out by dedicated teams.

Main operation assigned to Level 0 Servicing are the following:

- Interior cleaning
- Windscreen cleaning
- Restocking of onboard supplies
- Technical checks (on track)
- Functional controls by driver
- Trainset diagnosis system interrogation
- Low level repair and small parts replacement.

Level 1 - Depot Workshop Service and Maintenance

Level 1 Service and Maintenance operations are normally carried out every three or four days or on a km distance run basis, depending on train utilization.

The operations are carried out in a Depot Workshop, on the basis of a detailed schedule defined by the train management staff, taking into account the operation needs, the intervention timing defined by the train maintenance manual and the eventual train breakdown.

A specialized Depot Workshop, located preferably close to a train terminal station (around 10 km) is requested for Level 1 maintenance operations.

The Depot Workshop shall be equipped with the following main facilities:

- Parking tracks
- Trainset external washing installation
- Trainset under frame pressure washing installation
- Equipment for discharge, washing and restoring closed circuit toilets of a trainset
- Under floor wheel lathe
- Bogie replacement installation (for single bogie and for complete trainset bogies)
- Shed equipped with tracks specialized for trainset interior deep cleaning. The shed shall be equipped with electric power, water, compressed air, aspiration system, internal transport system…
- Shed equipped with tracks for trainset maintenance and components replacement. The shed shall be equipped with electric power, water, compressed air, aspiration system, internal transport system, cranes, ordinary and special equipment and tools

- Shed (or part of a shed) equipped with areas dedicated to revision and repair of basic components. The areas shall be equipped with electric power, water, compressed air, aspiration system, internal transport system, cranes, ordinary and special equipment and tools, welding equipment, components painting equipment, work benches, machine tools,….
- Shed equipped with tracks specialized for trainset final testing
- Shed (or part of a shed) dedicated to storage of spare parts and components in stock and to be sent to main workshop for major repair

Complete technical staffs, skilled for checks, controls, ordinary scheduled preventive maintenance, components replacement and repairs is required for Level 1 maintenance operations.

Administrative and a management staff are also required.

Level 1 Service and Maintenance main operations are as follows:

- Interior deep cleaning
- External complete washing and cleaning
- Under frame pressure washing
- Toilet discharge and restore to service (clean water tanks refilling)
- Restocking of onboard supplies
- Trainset refueling (sand, windscreen water, oil…)
- Technical checks (on track with central pit)
- Functional controls by driver and by simulators
- Trainset and local equipment diagnosis system interrogation
- Repair and parts replacement (when necessary)
- Wheel sets grinding (when necessary)
- Wheel sets and bogies replacement (when necessary)
- Scheduled preventive maintenance operations (different levels and frequency, according to the manufacturer maintenance manual)

Level 2 – Main Workshop Maintenance

Level 2 Maintenance operations are normally carried out in a specialized workshop,

Two main types of intervention are carried out in the workshop:

- Preventive heavy maintenance interventions
- Components overhaul and repair

Preventive heavy maintenance operation frequency and technical content are defined in the maintenance manual. Normally in the main workshop complete overhaul and refurbishment operations of trainsets are carried out.

When a component has to be stripped in a Depot Workshop because of a serious breakdown, it is sent to the workshop for restore and return.

Serious breakdown means a breakdown requiring specialized equipment and staff for the component repair.

For Level 2 operations a specialized workshop, located in a suitable area connected to the line operated by the trainsets, is requested.

The Main Workshop shall be equipped with the following main facilities:

- Parking tracks
- Trainset external and under frame pressure washing installation
- Equipment for discharge, washing and restore closed circuit toilets of a trainset
- Bogie replacement installation (for single bogie and for all trainset bogies)
- Shed equipped with tracks specialized for trainset coupling and uncoupling
- Shed equipped with tracks specialized for trainset final testing
- Shed equipped with tracks for trainset maintenance and components replacement. The shed shall be equipped with electric power, water, compressed air, aspiration system, internal transport system, cranes, ordinary and special equipment and tools
- Sheds (or areas of a shed) dedicated to revision and repair of stripped components. The areas shall be equipped with electric power, water, compressed air, aspiration system, internal transport system, cranes, ordinary and special equipment and tools, welding equipment, components painting equipment, complete vehicle body sanding and painting equipment, work benches, machine tools, testing facilities, wheels disassembling and assembling, wheel late equipment, traction motors rewinding, gearboxes repair, brake system components control and repair, axle boxes control and repair, suspension components and dampers control and repair, signaling and safety on board systems control and repair, bogie frame control and repair, ….
- Shed dedicated to storage of spare parts and components in stock and to be sent back to Depot Workshops following major repair

For Level 2 operation a complete technical staff, skilled for checks, controls, ordinary scheduled preventive maintenance, components replacement and repairs is requested as well as s management and administrative staff.

Main operations assigned to Level 2 Maintenance are the following:

- Repair of components broken down sent to the Main Workshop by the Depot Workshops
- General overhaul of trainset
- Car body heavy repair and painting
- Electrical, pneumatic and hydraulic systems overhaul and parts replacement
- Wheels and axles disassembling and replacement
- Bogies disassembling , re -profiling and overhaul
- Traction motors and gears disassembling and overhaul
- Air compressor disassembling and overhaul
- Main switch, pantographs and other electric components disassembling and overhaul
- Toilets overhaul

- Preventive heavy maintenance scheduled operations on trainset and single components (different levels and frequency, according to the maintenance manual)

Maintenance Schedule

Each manufacturer of trainsets defines and recommends a proper schedule for preventive maintenance operations.

The following table shows an example of a high speed trainset maintenance synthetic schedule.

In this scheme, basic maintenance schedule is divided into seven steps.

Maintenance tasks are assigned to the above said three levels.

Inspection Level	***Frequency***
Level 0	4,000 - 5,000 km
Level 1A	20,000 km
Level 1B	80,000 km
Level 1C	240,000 km
Level 1D	480,000 km
Level 2A	1,200,000 km
Level 2B	2,400,000 km

Each of the inspection level consists in the following main tasks:

- Every 4,000 – 5,000 km, a Level 0 inspection taking about 1½ hour lead time is undertaken, The waste collection tanks of WC closed toilets are emptied, and fresh water tanks are refilled, Eventual major defects (e.g. malfunctioning doors) are rectified, Furthermore, safety tests are conducted, This includes:
  - checking the pantograph force applied to the overhead line
  - cleaning and checking for cracks in the pantograph's rooftop insulators
  - inspecting transformers for leakage
  - checking the pantograph's current collector for wear
  - visual inspection of wheel sets and bogies,
- Every 20,000 kilometers, a Level 1A inspection taking about 2½ hour lead time is carried out, During this inspection, the brakes, the on-board signaling systems and the anti-skid equipment are checked as well, in addition to the operations of the previous level,
- After 80,000 kilometers, the train undergoes a Level 1B inspection, lasting eight hours, which includes brakes thorough check, as well as air conditioning and the bar-restaurant equipment check, The batteries are also checked, as well as the seats and the passenger information system,
- Once the train has reached 240,000 kilometers, the Level 1C inspection requires a check of the electric traction motors, the axle boxes, the wheel sets and the couplers, Like Level 1B inspection also Level 1C inspection is usually carried out in two modules taking eight hours each,
- About once a year (when reaching around 480,000 km) the Level 1D takes place, divided in three modules lasting eight hours each, Additionally to the other check-up phases, it

includes checks of the pneumatic systems, the transformer cooling, and maintenance works inside the passenger compartment,

- The Level 2A Revision is carried out after 1,2 million km, It includes a thorough checkup of all components of the train and is carried out in two five days modules,
- The seventh and final scheduled maintenance step is the Level 2B, which happens when the trains reaches 2,4 million kilometers, At this step all the train bogies are exchanged for new ones completely overhauled, All major train components are disassembled and checked, This step also takes two five days periods, considering the time for dismounting and replacing equipment, The time for off-line components overhaul has to be considered apart,

To reduce the lead time for preventive maintenance each trainset can be worked upon at up to four levels at a time (under frame, interior, outside, train roof) and the Depot Workshop layout is designed accordingly,

In addition, again to keep maintenance downtime at a minimum, fault reports are sent directly from the train to the Depot Workshop in advance via the on-board diagnostic computer system,