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Constructive Technology Assessment in Railway: The Case of High-Speed Train Industry

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Abstract

Technology assessment, understood as means of valuing socio-economic elements of technology development by employing participatory methods, is mainly seen as a policy-making tool, mostly focused on the impacts of technology. Less-known is the emerging perspective called constructive technology assessment, forward looking approach which is becoming popular among top-management and corporate boards, especially within the business sectors of high socio-economic impact. This is the case of the high-speed train manufacturing industry, which through societal inclusion envisages increasing its competitive advantage while decreasing market failure in the development of the next generation of high-speed trains.

This paper, which presents the results of a study conducted in 2011, proposes to address the under-researched domain, the technology strategic-intelligence strategy for the high-speed train product-development process. Constructive technology assessment was found to be the dominant practice, implemented by the technology-surveillance organizational structures from the early stage of the process.

Keywords: constructive technology assessment, technology-strategic intelligence, high-speed train manufacturing industry, corporations, technology pattern, railway.

1 Introduction

Today's European high-speed train manufacturers, which assembles and supplies the high-speed train vehicle[1] (or rolling stock), is a renewed, private, flourishing economic actor that focuses on the end-user and customer. Its origins are found in

[1] The definition of high-speed train is found in the EC Directive 96/58: "A high-speed train is a train capable of reaching speeds of over 200 km/h on upgraded conventional lines and of over 250 km/h on new lines designed specifically for high speeds".

the under-invested metalwork engineering industry dominated by political management. It faces in our days a new paradigm, with technology management relying more than ever on technology strategic-intelligence management tools to decode the complex system in which makes its technology decisions.

This results from the pressure that the European Commission exerted, during the last decade, on member states to invest in high-speed train networks as the backbone of the European long-distance transport system [1]. The determinants for this directive were European foreign oil dependency, traffic congestion, climate change and territorial integration.

In fact, looking at public data from the European Commission [2] and the International Union of Railways [3, 4], one can actually recognize the dimension that the revitalization of high-speed trains undertook: considering the increase of the rail transport speed, market share, network expansion and reduction in travelling time [5].

Today over 40% of European transport traffic for medium-length distances is made by high-speed trains. The commercial speed has reached a maximum of about 300 km/h for the majority of installed systems (Germany, Italy, United Kingdom), 310 km/h in Spain and 320 km km/h in France[2].

In one decade, Europe doubled its fleet from approximately 620 operating units in 2000, to 1.243 in 2010, becoming the largest fleet in the world; its dedicated network increased from less then 3.000km in 2000, to 6.214km in 2008 [2], with an additional 8.705km planned [3, 4].

The number of passengers on all existing lines (Germany, Belgium, Spain, France, Holland, Italy and the United Kingdom) increased from 15.2 billion passengers per km in 1990 to 92.33 billion in 2008 [2], a figure that is expected to triplicate by 2025 [3, 4].

In a circuit of major European cities (Paris, London, Amsterdam, Koln, Frankfurt and Brussels) from 1989 to 2009, travelling time has been reduced from 4 hours and 2 minutes to 2 hours and 24 minutes[3] - a 38% decrease [2].

It should be referred that although the drastically increasing figures just presented, the annual turnover of the high-speed trains for the manufacturing industry represents less than 10%. In fact it remains a small business but it is where

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[2] Source: Wikipedia, http://en.wikipedia.org/wiki/High-speed_rail, viewed in August 20th, 2012. For a comparative exercise one could also refer to the Japanese case. The Shinkansen reaches also 300 km/h (Wikipedia, http://en.wikipedia.org/wiki/N700_Series_Shinkansen, viewed in October 31st, 2012) and by the end of 2012 the commercial speed will be 320 km/h ("Tohoku Shinkansen Speed Increase: Phased speed increase after the extension to Shin-Aomori Station". East Japan Railway Company. 6 November 2007. Retrieved October 31st, 2012).

[3] The biggest reductions have been achieved in the routes London-Brussels (from 4 hours and 52 minutes to 1 hour and 55 minutes, -62%) and London-Paris (from 5 hours and 12 minutes to 2 hour and 15 minutes, -57%), in this case due to the Eurotunnel. Other significant reductions are Paris-Brussels (from 2 hours and 25 minutes to 1 hour and 22 minutes, -43%) and Köln-Frankfurt (from 2 hours and 10 minutes to 1 hour and 10 minutes, -46%) [2]. Today is even possible to travel from Stuttgart to Paris in 3 hours and 41 minutes (source: DBahn at http://reiseauskunft.bahn.de/bin/query.exe/d, viewed in June 8th, 2012).

in railways is found the highest technological content and complexity in designing and manufacturing, of relevance for the purpose of this paper.

Furthermore, the European railway sector reform also introduced reorganization of competition, management, price pressure, reduction of employment in train operator companies, and shifted design, maintenance and technology research to the manufacturers [5].

Altogether, that reform pushed for greater coherence between expenditure, technologies, knowledge and policy needs [6]. Technology actors become confronted with issues of competitiveness, environment, safety, public acceptability and other aspects of "social quality", to use Rip's [7] terminology. To comply the overall railway manufacturing industry invests (not only in high-speed) about 500 million Euro a year in new developments [5].

The manufacturing industry soon understood it could not manage technology development on a basis of trail-and-error associated to high-investment costs, as had happened in the past. Today it develops its products on a non-linear system of multi-level players, contrasting with the previous linear system and its, still remaining, culture of secrecy and reluctance at exchanging information.

Collaborative technology development, involving the participation of all stakeholders including user groups and lead consumers, started to be seen by the train manufacturing industry as relevant in their "strategic intelligence" approaches [8] to anticipate "integration" of new technology in train operations and markets; to assure "admissibility" according to regulations; and to foresee "acceptance" by customers and end-users [7]. Top management expects to increase acceptance of their technology decisions by the public, clients and governments, as a means to mitigate market failure and ensure a return on their investment.

However technological interests greatly defer among stakeholders. End-users could not care less about the train being equipped with a permanent magnet motor or an asynchronous motor as train operators do. This way, as it will be put to evidence, constructive technology assessment is found as the dominant practice addressing such diversity of technological levels of interest, implemented by technology-surveillance organizational structures from the early stage of technology development process, through collaborative R&D projects, scientific papers, conferences, workshops, trade shows, training sessions and, most recently, consultations in social networks.

The present paper reports on the results of a first-time ever study bridging social sciences with innovation management and engineering within the railway sector. Based on Moretto *et al.* [9] findings resulting from the empirical evidence obtained from their study of the major European high-speed train manufacturing industry, it contributes to further extend conceptual models by Rip *et al*. [7], Pavitt [10], Castellacci [11] and Lichtenthaler [12] to the high-speed train manufacturing industry.

The following sections propose therefore to unveil the under-researched domain: the technology strategic-intelligence strategy of the high-speed train product-development process; bringing to light the practice of constructive technology assessment current in this highly technological firms.

2 Theoretical background

This paper builds on the analysis of theoretical references found in the technology assessment literature, conferring to it a share in strategic-intelligence strategies that address complex innovation systems.

Technology assessment's evolutionary function (from "early warning" as a support for policy-making, to "problem and end-users driven" instruments practiced by interest groups and corporations) is generally recognized by the scientific community, as found in TAMI [14], STOA [15] and more recently in PACITA [16].

The European literature focuses on a consensual conceptualization of technology assessment, (Bechmann *et al.* [17], Grunwald [18, 19] and Rip *et al*. [7]); and on defining a common methodology, (TAMI report [14]), which results from the diversity of perspectives and functional approaches.

It is actually in this exercise of defining technology assessment that Kuhlmann [20, 21] first associates technology assessment with "strategic intelligence" as part of complex innovation systems[4], equivalent to other strategic intelligence forms, namely, technology forecasting, technology foresight, evaluation and road mapping.

Smits *et al.* [8] further elaborates on technology assessment's distinctive elements, such as: its focus on decision-making support (instead of technology developments as in forecasting and road mapping); problem orientation (as opposed to early-warning functions, or evaluation as in foresight); and intensive interaction with a wide variety of actors.

In turn, Rip *et al.* [7] extends technology assessment function beyond policy-making, to include non-governmental actors, (*e.g.* corporations and interests groups). They add the concept of anticipation of future technology developments (not limited to early warning function) and contextualize this anticipation in relation with markets and society. Furthermore, these authors consider the feedback into relevant decisions as the overall function of this tool.

Studying the case of the nano-technology industry, Rip transposes to the early stage of the technology development process the participatory practices that were once found within the impacts of policy-targeted technology-assessment perspectives. In this manner, constructive technology assessment emerges from the attempt of corporations and interest groups to address societal issues from an early stage of what the author calls "product construction process", by employing dialogue and early interaction among actors while identifying their distinctive

[4] Kuhlmann [20, 21] and later Smits [8], present a strong influence from evolutionary and neo-institutionalist economics: Nelson & Winter, 1982; Dosi, 1988; Freeman, 1987; Lundvall, 1992; advocating innovative complex systems; and von Hippel, 1988, 2005; Akrich, 1995; Oudshoorn & Pinch, 2003; highlight the importance of user involvement in innovation processes. These authors have significantly contributed to enlarge technology assessment domains from purely assisting linear policy-making to strategic intelligence.

technological interests.

Moretto *et al.* [9, 13] contributes further by adjusting the application of the above-referred theoretical references to the specificity of the railway manufacturing industry; particularly, constructive technology assessment [7, 22] to the complex technology development process of the high-speed train.

Building on the findings of the cited authors, this paper presents the case study of the high-speed train manufacturing industry technology development process, analysed from different angles, using complementary analytical and taxonomic models found in the literature.

This systemic analysis refers to Castellacci's [11] taxonomy model, mapping the high-speed train manufacturing industry within the technology change pattern proposed by the author. Building on Pavitt [10], Castellacci's [11] taxonomy is a useful tool to define the technology pattern in which the high-speed train is designed, developed and assembled; and to define technology trajectories, relevant vertical linkages and inter-actor knowledge exchange, to finally arrive at the identification of technology assessment-type activities.

The present work contributes to Castellacci's taxonomy model, applying it to a new group of firms not considered by the author, and suggesting some adjustments. Castellacci makes a slight reference to rail-track as part of the "physical infrastructure" located within the "infrastructure services" technology pattern, but he does not refer to train vehicles. Applying his classification model, we can match the high-speed train manufacturing industry to his description of the "scale intensive" sub-pattern, which belongs to "mass-production goods". However the high-speed train manufacturing industry is producing on a small-scale. In his model, Castellacci only considers the Fordist-paradigm type of industries, as he refers to them, citing the example of the motor vehicle industry [11]. Therefore, Moretto *et al.* [9] suggests refer to this technology pattern as goods production in a broad sense.

Likewise, Moretto *et al.* [9] suggests to change the denomination of the sub-pattern "scale intensive" to "scale and volume intensive". The reason for that is because high-speed train manufacturers, despite producing on a small-scale, use a large volume of technology intensive solutions due to the size of a train.

Moreover, Moretto *et al.* [9] suggests to broaden the scope of Castellacci's term "personal goods and services" to a more general denomination such as "personal and public goods and services", to comprise train operators in the technology pattern.

The organizational analysis of the present paper builds on Lichtenthaler's [12] mapping of corporations' technology-surveillance structures in different sectors. The present work contributes to the author's model by identifying the organizational structures of the high-speed train manufacturing industry that carry out constructive technology assessment.

Finally, the present paper also integrates the results of the first round of interviews to a demonstrative sample of European research institutes, component suppliers and certification bodies as well as train-operators and end-users, to validate the findings of Moretto *et al.* [9] in relation to the studied manufacturers.

3 Sector technology pattern

It is commonly known that the decision to construct a high-speed train network and to acquire high-speed train vehicles is a controversial subject for governments and their citizens, with high media attention[5]. Projects of that kind involve a significant amount of public money[6] but not necessarily result in participatory public debates, as shown by Boavida, Cabrita & Moretto [23], making it a matter of political decision.

Not so mediatised there are other types of decisions concerning the technological content of the high-speed train. They involve a complex and interlinked multi-actor system, comprising manufacturers, suppliers, train operators, track-work-companies and infrastructure managers, as described further in Figures 1 and 2.

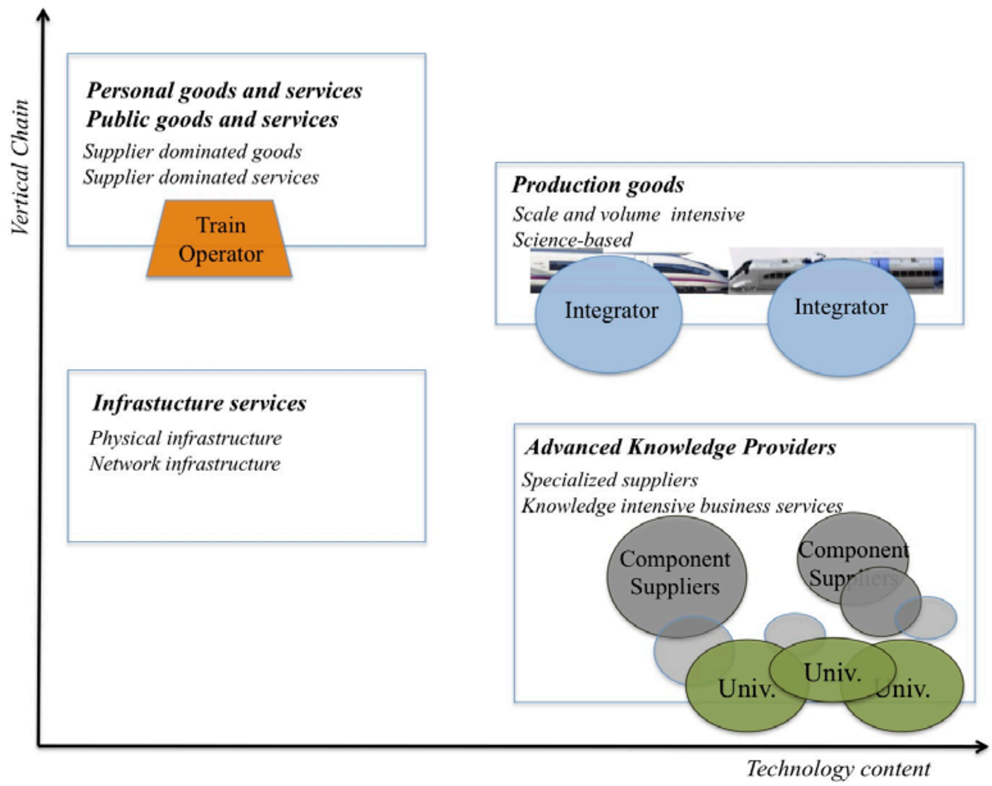

Figure 1: High-speed train multi-actor technology system within Castellacci's adapted taxonomy model

[5] There are cases such as the high-speed train link Lisbon/Madrid where the Portuguese government fearing the impacts of the first wave of the global economic crisis in 2008 favoured the project as part of its economic recovery-plan. On the other end there are cases alike to the one of the mixed rail link Turin-Lyon, where Italian citizens got organized against the project, for environmental reasons mainly, capable of gaining some weight.

[6] According to UIC [3, 4] the magnitude of costs of high-speed systems (average costs in Europe) are: Construction of 1km of a new high-speed line 12-30 Million EUR; Maintenance of 1 km of new high-speed line 70,000 EUR per year; Cost of a high-speed train (350 places) 20-25M EUR; Maintenance of a high-speed train 1Million EUR per year (2 EUR/km – 5000,000 km / train & year).

These actors address governmental policy targets (such as oil dependence, traffic congestion, safety, climate change, territorial integration, competitiveness), end-users expectations (journey time, connectivity, ticket fare, frequency and comfort, to name some) and sector's specific requirements (such as modularity, standardization, safety and costs optimization). At the centre of the decision are today manufacturers (before were the train operators), assuming the majority of the development costs.

Figure 1 represents the high-speed train supply-chain multi-actor technology system (their complex and interlinked relations will be described after in Figure 2). The adapted Castellacci's taxonomy model is used to scale each actor's position within the chain and the level of technology content their products and services provide.

The central actor of technology decisions, the high-speed train manufacturer (also called system integrator), is found at the technology regime "production of goods", sub-pattern "scale and volume intensive". It is an intermediate level of the supply-chain, of high technology content.

According to Castellacci [11], in that regime, firms receive technological inputs from "advanced-knowledge providers", including "specialized suppliers" and "knowledge intensive business services", while, in turn, providing technological outputs (new products), which are used by "infrastructure services", as well as by "providers of goods and services".

High-speed train manufacturers are typically large companies, worldwide suppliers, with about three to four major players in the European market, with a strong national identity defended by the headquarters [24]. Profitability depends on their standardized production volume [11].

Similar to the automotive industry referred by Castellacci [11], the high-speed train manufacturing industry has the capacity to develop new products and processes internally, with its in-house R&D facilities, on its own or in conjunction with suppliers, clients and end-users.

Another actor part of the represented system in figure 1 is the component supplier. It is found in the "advanced knowledge providers" technology regime [11], at the bottom of the vertical supply-chain provider of high technology contents. Some of these suppliers are from the same sector as the high-speed train manufacturers, working on an exclusivity basis with their clients.

Alike the automotive industry [11], in the high-speed train, those component suppliers are majorly "specialized suppliers" of equipment and precision instruments, with a high-level of technological capability, able to meet the tight requirements imposed.

In a smaller but increasing scale, they are also "knowledge-intensive business services", such as providers of communication and navigation systems on board the train or providers of virtual maintenance systems. But that is not all, with the greater technology complexity of the high-speed train, manufacturers are expanding the range of contracted services and relying more on these companies to design sub-systems.

Academia is as well in this same sub-pattern “knowledge-intensive business services”, in the form of spin-offs or knowledge centres. They are increasingly becoming partners in commercial offers and contractor of knowledge services by manufacturers and component suppliers.

Other type of actor of the system is the train operator. Despite not being referred to in any of Castellacci’s technology regimes, they easily meet the characteristics of “personal goods and services”, sub-pattern “supplier dominated services”, at the top-left of the chart. It corresponds to a regime with low technology content and receiver of technology from the other described regimes.

It should be noted that such classification is not so linear. Today traces remain of the sector’s recent history, when the train operator drove technology development. That was the case of the first French TGV and the first and second generation of the German ICE. However, recent trends indicate that the role of train operators in this respect is decreasing in Europe (Japan being an exception) [3].

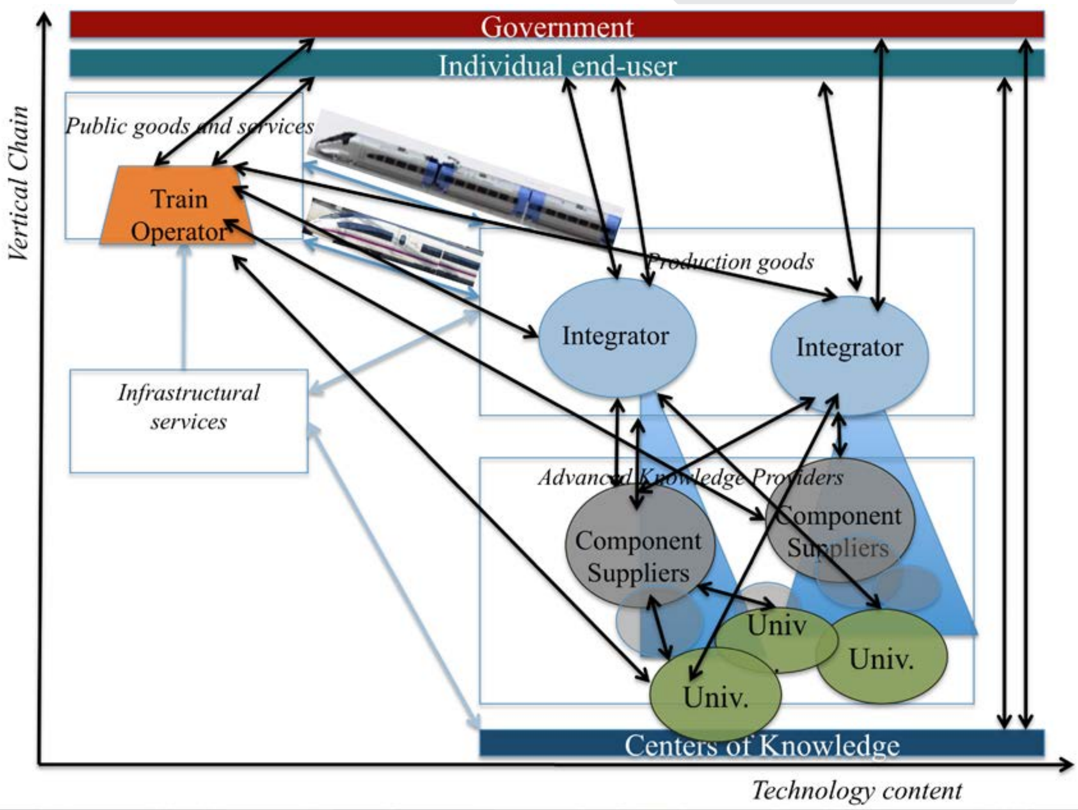

Figure 2: High-speed train multi-actor technology relations within Castellacci’s adapted taxonomy model

Figure 2 represents multi-actor complex and interlinked technology relations in the high-speed train technology development trajectories. It adds to the previous figure 1 external actors to the technology supply-chain, such as governments, end-users and educational institutions, also part (directly or indirectly) in the technology development process.

Multi-actor technology relations comprise mutual dependencies (conferring complexity) and interactions (interlinking actors). Dependencies vary. They are quite tight between manufacturers and the suppliers. But they can be rather vague between academia and manufacturers and between the academia and suppliers, subject to discontinuities. Interactions, in its turn, occur in all directions. They confer dynamics to the different technology regimes. Interactions can be experimental or established.

The dominant type of multi-actor relations (of dependencies and interactions) is determined by the stage of technology development: if in a pre-competitive stage (scanning for technology developments and opportunities as well as for future market needs) or in a competitive stage (preparing a commercial offer).

In the pre-competitive stage the combination of relations between actors has a variable geometry, reflecting vague dependencies and exploratory interactions. Technology relations are mainly focused at anticipating major technology needs, trends and opportunities in the medium future. Actors envisage to anticipate others technology capacity and interests through collaborative research projects, market analysis and survey their competitors. Information flows quite openly, but its disclosure is selective. Competitors can appear in the same project, as for instance in collaborative research projects of non-core technologies (see section 4).

At the competitive stage of the high-speed train technology development, multi-actor relations and knowledge exchange takes the form of a pyramid, reflecting tight dependencies and established interactions. At the top of each pyramid is the consortium leader, *e.g.* the technology integrator (or assembly manufacturer), or in some cases the supplier of major parts. A pyramid can also be lead by two major integrators (examples are the high speed trains AVE class S-102*, 2nd series, manufactured by Talgo and Bombardier).

There are as many pyramid formations as number of bids for a particular call for tender. They integrate actors with demonstrated capacity of supplying the component or service required by the integrator, meeting tight specifications at low prices. Relations of mutual-dependencies are dominant here as such requires a major technical and economic effort from the supplier (in many cases a return is only seen in a long-term relation).

Each pyramid leader possesses almost all the technologies to bid and usually is the final interface with the client, the train operator. Such confers to the leader the ability to acquire the technological knowledge and solutions required by the customer. The source of information is the tender specifications, if available, or, if not, anticipated with technology assessment-type of activities. Then, the leader passes the information to the sub-levels, and those pass it on successively to the subsequent level of supplier, and so on. The sub-system suppliers' feed back the consortium leader with specific know-how and technology solutions they have in their specific fields.

Manufacturers to overcome the complex multi-actor relations as described practices constructive technology assessment, mainly at the pre-competitive stage of the technology development process. Such actor's centric instrument is mostly focused at identifying interactions and potential dependencies as well as unveil each ones technology interests and capabilities; resulting in the anticipation of end-users' expectations, political and market conditions (including to a certain extend tender specifications and certification processes), or even to scan specific technology solutions being developed locally in the medium and long future.

The manufacturing industry looks upon universities as a partner, for undertaking constructive technology assessment-type activities. They are a direct source of emerging disruptive technologies, knowledge of local market constraints and end-users' expectations, and they are in direct relation with the local governments.

Constructive technology assessment is also practiced as means to arrive at co-responsible technology development and as means of legitimising technology development.

4 Product development process

The high-speed train is a vehicle, defined as a highly sophisticated technology product system, with a complex integration system of components, with different levels of technology intensity, and to which manufacturers assume different degrees of open innovation [9], as represented in the following Figure 3.

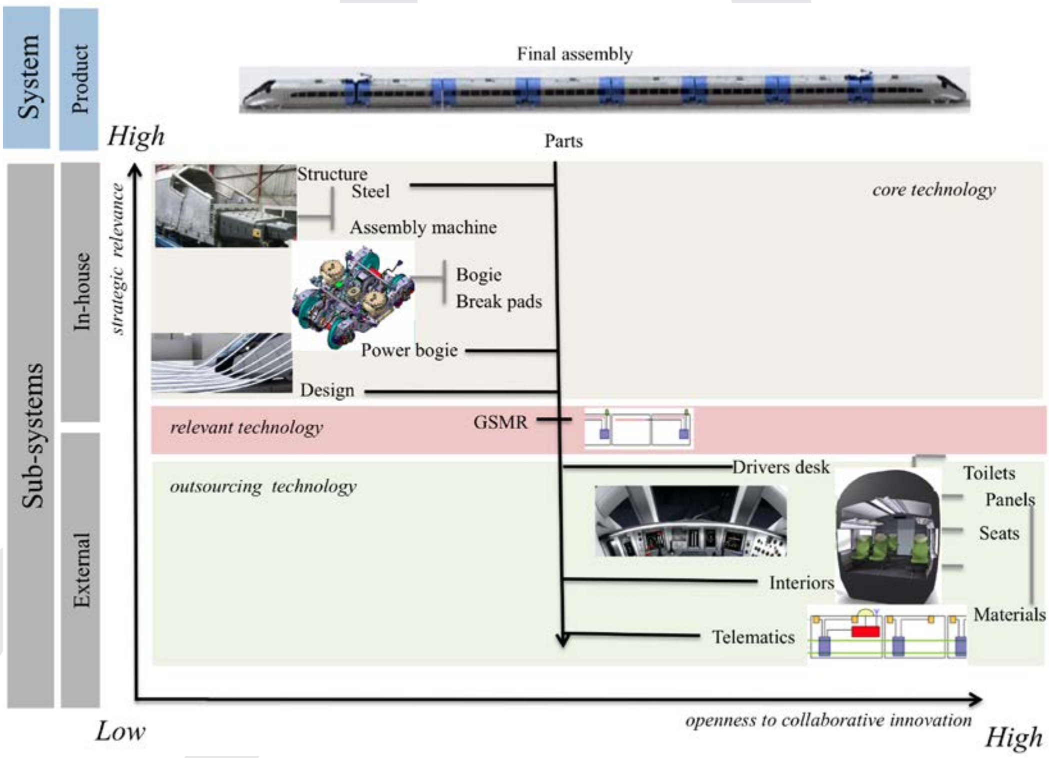

Figure 3: High-speed train technological system and level of openness to collaborative R&D

Figure 3 results from information collected from the findings of Boavida and Moretto [24] and informal interviews with firms, structured in a product tree, using Pavitt's [10] products classification method.

At the top of the product tree are found core technology areas, such as structural parts, bogies, energy conversion and safety systems. They are highly protected by train integrators and not usually subject to collaborative research. Co-development is almost inexistent and the level of ownership of end-results is high. These parts are developed in-house by the centers of excellence and design of the manufacturing industry, directly coordinated by top-management, subject to a high level of secrecy and protection from competitors. If cooperation exists at this level, it is mainly held with universities, subject to strict confidentiality agreements, with manufacturers claiming ownership of the technology development.

At the middle range of the tree, this technology is relevant to the manufacturers but falls outside its core engineering capabilities, such as rail traffic sigh systems telecommunications or virtual maintenance systems. At this level, manufacturers tend to co-develop the technology, mostly on a bilateral basis, with other partners such as component suppliers or external knowledge centres and academia. In many cases, partners are from the same sector, but not necessarily; and are restrained by an exclusivity relationship with integrators. Often partners are located in the proximity of the production site. However, cases exist where are manufacturing companies sending technology envoys to component suppliers located in a different region in the world. In this case, the level of co-development is low and ownership of end-results tends to be high. The instruments used are often bilateral, confidential agreements between a manufacturer and a co-developer.

The technology subject to outsourcing, such as interiors and telematics, is found at the bottom of the tree. At this last level, the technology development is quite open and it is where we find evidence of constructive technology assessment [9, 13]. Manufacturers promote these activities at a strategic level. Usually, it is the local branch or special technology envoy that informs the center of excellence and design of a technology development opportunity. Specific targeted groups are consulted, which includes user groups formed by end-users, customers, certification bodies, as well as other relevant entities; and collaborative research is promoted. Collaborative research is used to anticipate specific client needs, local market constraints and end-users' expectations. Technology development mainly occurs in the world region of the client, with local based suppliers. The level of co-development is high, and ownership of end-results is low. The relationship between integrators and its partners is dominated by consortium agreements on an open basis, *e.g.* not subject to exclusivity. In particular cases, such as those addressing modularization and standardization, technology development could also involve competitors.

Seabra Pereira [5] adds to Boavida and Moretto's [24] product tree. According to this author, manufacturing industry searches for innovative solutions with two main objectives: performance and attractiveness, including compliance.

To solve performance problems, the manufacturing industry targets technology developments, for example, those that concern wheel/rail contact fatigue, design/simulation tools, system integration, materials (lightweight), structures (optimization and design for manufacture), aeroacoustics (noise abatement), mechatronics (wheel/rail, steering and suspensions). These fall within the top and middle layers of the product tree, with restricted openness to collaborative innovation.

On the other hand, to foster more specific research, tailored to achieve defined outcomes to make the vehicle attractive to customers and compliant with local regulations, the manufacturing industry targets technology developments in areas such as energy power, biomechanics, human/machine interface, environmental friendliness, safety and comfort; these fall within the lower layer of the product tree, including telematics, materials, cabin interiors, *etc.*

In this respect, the findings of Moretto *et al.* [9] consider that it is mainly in this last referred group of technology developments that societal embedding occurs from the concept and design of the high-speed train technology development. The manufacturing industry uses constructive technology assessment [7] to align its technology developments at an early stage with future external constraints, so that risks of market failure are mitigated.

Looking forward, the ERRAC [25] foresees that in the next decades the challenges posed to this sector will shift from policy, pushing for a full interoperable and modern transport system, to end-users' rapidly changing mobility patterns. If that is the case, product attractiveness through participatory methods resulting in societal embedding will become increasingly relevant for the success of the next generations of high-speed trains.

5 Technology decision-making trajectories

The high-speed train (in particular the very high-speed one) was commonly considered disruptive when introduced. That is no longer the case as for those manufacturers mastering the technology. Nevertheless, it is yet disruptive for new comers wishing assembling it or starting operations. This technology is subject to continuous development, which may result from mature technology transfer from other sectors such as aeronautics and airspace, in regards to lightweight structures, for instance.

At present, technology development is mainly focused on standardization, modularization, safety and the need to meet specific socio-cultural requirements imposed by the operator company. However innovation in this industry is not linear, characterized by long technology trajectories[7], subject to heavy certification procedures and cost pressure from its clients.

From empirical observation of the manufacturing industry contrasted with stakeholders interviews, it can be said that the technology path, from R&D

[7] Technology trajectory in the industry: three to five years between technical development and final product and; four to five years from responding to a tender and its final commercialization [4].

development to product certification and operation, follow two different trajectories: technical and commercial, involving specific decision-making steps set by internal corporative procedures [9].

Figures 4 and 5 describe said trajectories and decision-making processes, constructed on the common elements presented by the two major high-speed train manufacturers, studied by Moretto *et al.* [9].

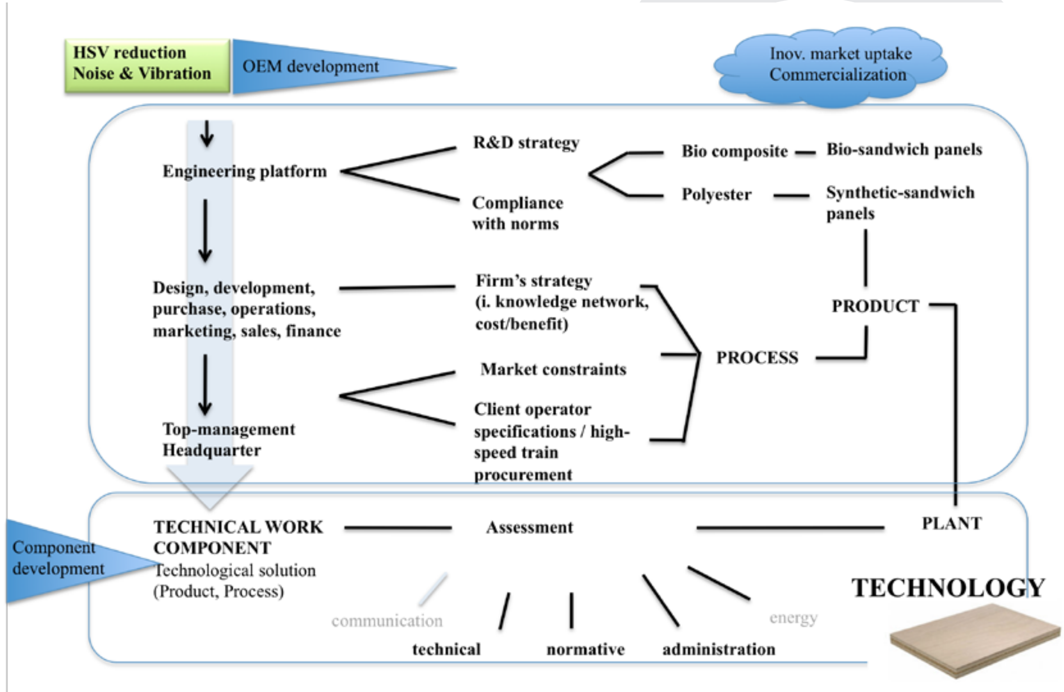

Figure 4: Technical trajectory

Figure 4 represents the high-speed train manufacturers' technical trajectory initiated from a technology driver, for example: noise and vibration abetment of the rail car with innovative sandwich panels. In this case, technology development to address a technical problem usually starts in-house at the engineering platform located in one of the centres of excellence or design specialized in the subject. The engineers work on two or more technology solutions of sandwich panels, for example: one on bio-materials and other on synthetic materials. As integrators do not manufacture the panels, the technology solution must be found externally and adapted to the train.

As mentioned before, manufacturers considers this type of technology a non-core technology, subject to outsourcing; therefore the technology development is carried out in cooperation with first-tier panel suppliers and could also involve second-tier materials suppliers. At this stage, the platform of engineers would be located in a strategically located centre of excellence or design, or geographically close to the headquarters.

If one of the technical solutions is mechanically viable, the technical director will carry out a preliminary SWOT analysis, and a final verification of compliance with tight norms, *e.g.* fire and smoke. Once approved, the technical director will present it to middle management who is responsible for decision-making, involving other units such as design, purchase, production operations, marketing, sales and financing. At this level, decision-making is based on the sum of the different strategies guiding each one of the units and on a cost-benefit analysis. A transversal knowledge network is formed internally, multiplying each individual knowledge network from the individual departments with external partners.

After this stage, the new technology solution, (*i.e.* reducing noise and vibration of the high-speed train car) is no longer a technical matter only. In some cases, it can happen that the final provider turns out not to be the one co-developing the solution, or more than one supplier is required by the client operator company.

The new technical solution, accompanied with an interdepartmental analysis (normative, socio-economic and financial) is then brought to the top management for final approval. It is at this level that the technical decision-making trajectory crosses with the commercial one.

Figure 5 represents the high-speed train manufacturers' commercial trajectory, initiated from an economic driver (or business opportunity), for example: the prospect of opening an international tender by the Portuguese railway operator for the acquisition of high-speed trains, accompanied with political measures.

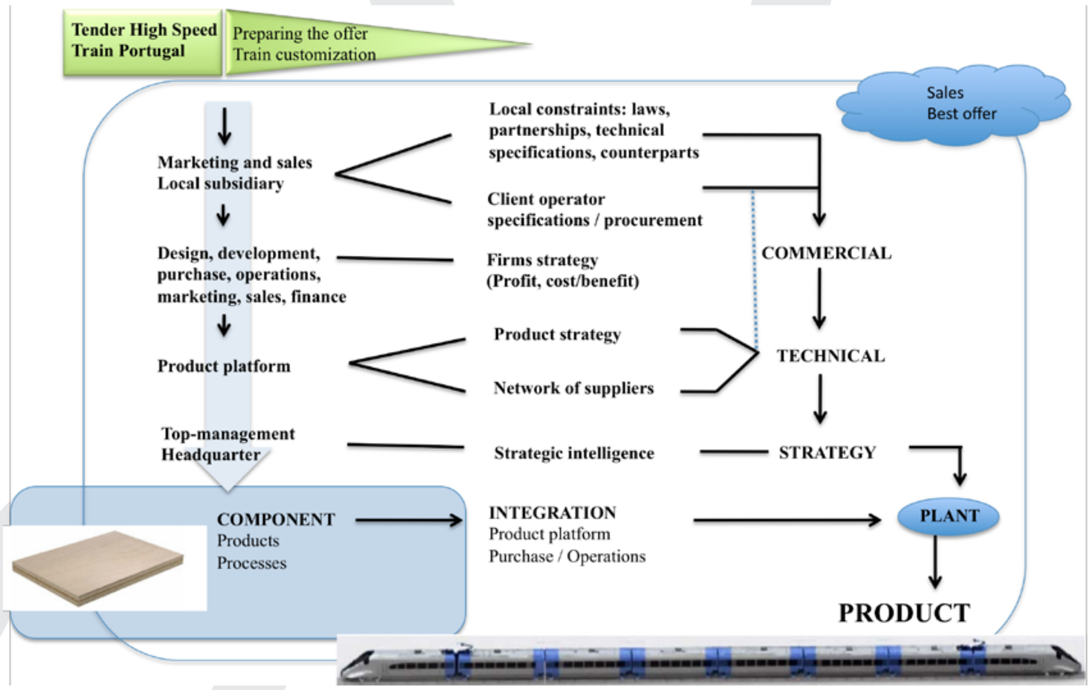

Figure 5: Commercial trajectory

The trajectory begins with the local subsidiary, at its marketing unit located close to the customer, based on knowledge of local constraints such as laws, partnerships, counterparts and technical specifications. The subsidiary also has information from local informers and technology assessment activities on relevant technical and socio-economic elements of procurement, which in the majority of cases are measures to create jobs, retain knowhow or attract centres of excellence and design from the multinationals [24].

Once the marketing unit has collected all relevant information necessary to build the offer, it launches the internal mechanisms for decision-making, regarding the type of vehicle and technical developments necessary to adapt it to the local customer requirements. At this stage, the relevant units from headquarters, *i.e.*, design, technical, operations and finance, take part in the matter. A decision is made based on a cost/benefit analysis in compliance with the manufacturer's strategy and reported to the top-management in the headquarters. As in the technical trajectory, it is the responsibility of top management to decide whether to implement or not the offer of high-speed trains, and to decide on the strategy to follow.

As mentioned before, it is at this final stage where the two trajectories, technical and commercial, meet. It is up to top-management from the headquarters, together with top-management from the involved subsidiary, to match the technical developments with the commercial offer, as way to build a competitive offer. In both trajectories, top-management in the headquarters functions as referee, reserving the final decision. Therefore, they count on a third additional element of information, which is technology strategy intelligence.

In line with the above description, Moretto *et al.* [9] have identified that technology assessment activities are mostly performed when the two trajectories meet, supporting top management's final decisions on the technology development options for the high-speed train, by adding societal information, collected at a strategic intelligence level, to the technical and commercial ones. Moreover, the authors point out that both trajectories also have in their process societal embedding performed at some stage in the described processes.

At the technical trajectory, the engineering platform might perform technology assessment with exploratory contacts with local universities and component suppliers, to solve a technological problem, especially if they are from a lead market or are a lead supplier. However, within this trajectory, technology assessment activities mainly occur at top-management level when confronted with the final decision whether to integrate or not the technology solution in the train. Top management generally uses information from home-based international intelligent units to confront the technology solution, developed by its team of engineers, with technology mega-trends. Top management can also use information from technology envoys, scanning structures and external structures, in targeted markets (lead markets or potential markets), to check whether the technology developed in-house meets specific market constraints and the expected procurement specifications.

Within the commercial trajectory, technology assessment is performed with high-speed train manufacturers promoting local actors' participatory and constructive activities as means to collect end-users' and clients' information on the technical and socio-economic elements of procurement. Then, the results of this exercise are embedded in the technology development of the high-speed train vehicle to be offered to the concerned train operator. The local subsidiary, as a scanning structure, in interaction with local informers and universities, promotes participatory and collaborative activities to anticipate customers' technical and socio-economic elements of procurement and end-users' expectations. Top management, in turn, uses technology assessment to match technical developments of the high-speed train with commercial specifications given by the subsidiary.

As mentioned earlier in this paper, decision to implement a new high-speed line and operating it is highly political. Constructing a new high-speed line and acquiring a certain number of high-speed trains represent a quite large investment. As a consequence, it is very often required that preferences, when possible, be given to the local industry and academia. In some countries such as in the United States of America with the "buy American act" it is mandatory that 60% of the value to be located in the country. Or the Portuguese law (Decreto-Lei n.º 18/2008) requiring one percent of R&D investment for bids above 25 million Euro [24]. This explains why manufacturing industry, as referred, consider development or production with local companies. Similar reasons for developments with local universities, providing local content, demonstrate R&D investment in the country and influencing decision-making.

6 Technology surveillance structure

Technology strategic intelligence is an institutionalized practice by the high-speed train manufacturing industry, covering surveillance. The complexity of assembly the train integrating a wide variety high-technological components and services, makes it the key instrument to decode the complex system changes in which technology decisions are taken, to anticipate future customer needs, identifying disruptive technology and mitigate failure of new technologies in the market. It functions also as an alert mechanism to new policy initiatives and to anticipate the socio-economic impacts of technology options.

In the high-speed train manufacturing industry, technology strategic intelligence appears as a supra-organizational structure, embracing its internal departments' organizations and anchored in members-staff, with ramifications to external actors, from industry, train operators, academia, governments and society. It mainly appears as a structured and hierarchical process, allowing for some degree of hybrid and informal practices. Technology strategic intelligence is supported by a series of instruments identified by Boavida and Moretto [24], such as knowledge platforms and partnerships; R&D projects; and education and training.

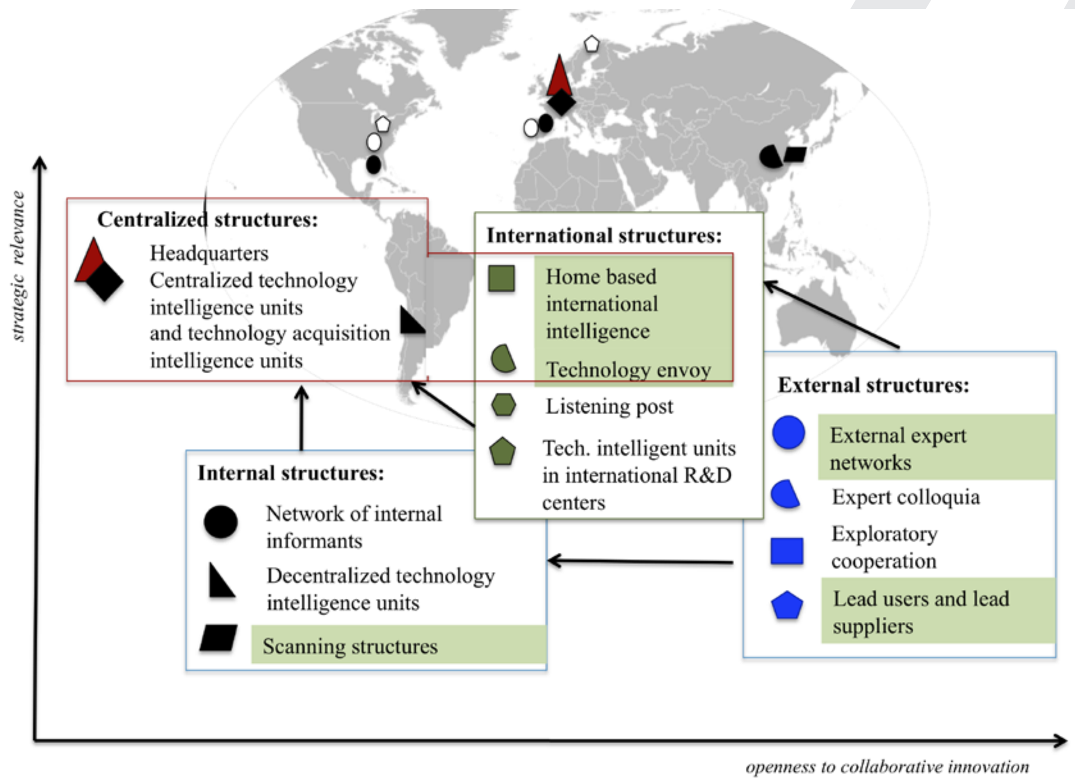

Figure 6: Technology surveillance organization

From the application of Lichtenthaler's [12] work, Figure 6 aims at presenting a systematic overview of the way technology strategic-intelligence process is organized in the high-speed train manufacturing industry organizational structure, referring to the relevant elements presented by the author. These elements were grouped in sub-structures and positioned in terms of strategic relevance and degree of openness to collaborative R&D.

As the figure shows, manufacturing centres of excellence and design in core-technology areas are usually located at the headquarters or at the sites where the train is assembled. They combine the "central technology intelligence unit" and the "central technology acquisition intelligence unit" (for definitions see Lichtenthaler, [12]) who look at the competitive aspects of technology strategy-making and alliance-management processes such as start-up companies, university technology transfer and control of R&D projects. They are the higher structure to which top-management refers to. The instruments they employ are: reporting analysis and periodic meetings with the other structure forms, mapping of technology developments, R&D projects, and future exercises such as forecasting, scenario and road mapping. Technology assessment activities were not found, as they mainly focus on technology itself and early warning functions.

Figure 6 also illustrates the fact that strategic intelligence is likewise present in the manufacturers' internal structures, such as the "networks of internal informants", present in the different departments and subsidiaries spread around the world; "decentralized technology intelligence units" focus on middle management and non-core technology areas; additional information channels, such as "scanning structures", are supported in most cases by subsidiaries' top-management (for definitions see Lichtenthaler [12]). These internal structures report back to the "centralized technology intelligence unit". The central unit can request the internal structures to address a particular subject or they can be initiators. The leadership of the internal structures depends on the strategic relevance given by the central structure and top management to the technology at stake. These internal structures are anchored in the departments involved in commercial projects or mature technologies, as seen in the described technology trajectories. The instruments used are reports, meetings, R&D projects, site tests and certifications.

Moretto *et al.* [9] show that constructive technology assessment activities are also found in "scanning structures" carried out by top managers from local subsidiaries, as ways to monitor the local market. These activities include consultations to local relevant actors (industry, universities, train operators, certification bodies, associations, etc) and lead-users considering socio-economic aspects (employment, local policies, social constraints, environment, etc). Constructive technology assessment activities range from a simple scanning on the local impact of the high-speed train technology to the complexity of customizing the train to the local market constraints. The participatory method of enquiries involving the people who use the train is now complemented by open, online debates in social networks.

Continuing the description of Figure 6, the high-speed train manufacturing industry also have an external technology-intelligence organizational structure which includes: "external expert networks" (as in the case of the European Rail Research Council (ERRAC)[8]); "external expert *colloquia*" (to identify possible technology directions from universities and consultants); "exploratory cooperation" (usually with suppliers from other sectors and universities, as means to test the application of matured technologies in the high-speed train, or to train potential local suppliers in areas subject to outsourcing); "lead users and lead suppliers" (that can also be considered as external experts for benchmarking purposes). For definitions see Lichtenthaler [12]. The instruments used are the ones found in other structures, such as meetings, R&D projects, site tests, certifications and future exercises.

In projection exercises, manufacturers practice technology assessment mainly at the level of "external experts networks" and "lead users and lead suppliers", with workshops, meetings, and technology agenda-setting and dissemination activities. At this level, information on trends is quite openly shared and has a long-term perspective.

The model in Figure 6 also shows that, as multinationals, the high-speed train manufacturing industries have international intelligence units, such as "home-based international technology intelligence" located at the central intelligence unit, responsible for scanning pro-actively for relevant information from all the other

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[8] ERRAC is the European Technology Platform for rail. This technology platform thinks about the future technology and market trends for the rail sector, also involving competitor industries

organizational structures, including visiting those structures around the world and demanding information, rather than waiting for reports; and "technology envoys", which are workers sent to a specific market to build up an external network with local clients and institutions (for definitions see Lichtenthaler [12]). International centers of competence and design may also have technology intelligence units, if installed in a strategic leading market or region of knowledge. The most common instruments are R&D projects, future scenarios and scanning activities.

Finally, according to Moretto *et al.* [9], constructive technology assessment is found at the level of "home-based international technology intelligence" and "technology envoys". Despite being oriented towards technology, like the centralized technology units, their main focus is to support decision-making based on a problem or project orientation in an intensive interaction with a wide variety of actors at national (overlapping with "scanning structures") or regional levels.

7 Strategic intelligence

Figure 7, adapted from Moretto *et al.* [9], sums up the function of constructive technology assessment, as defined in Rip *et al.* [7], within the high-speed train manufacturing industry described in the previous sections. It is anchored within the firms strategic-intelligence strategy, implemented by the technology surveillance's organizational structure, occurring from an early stage of product development.

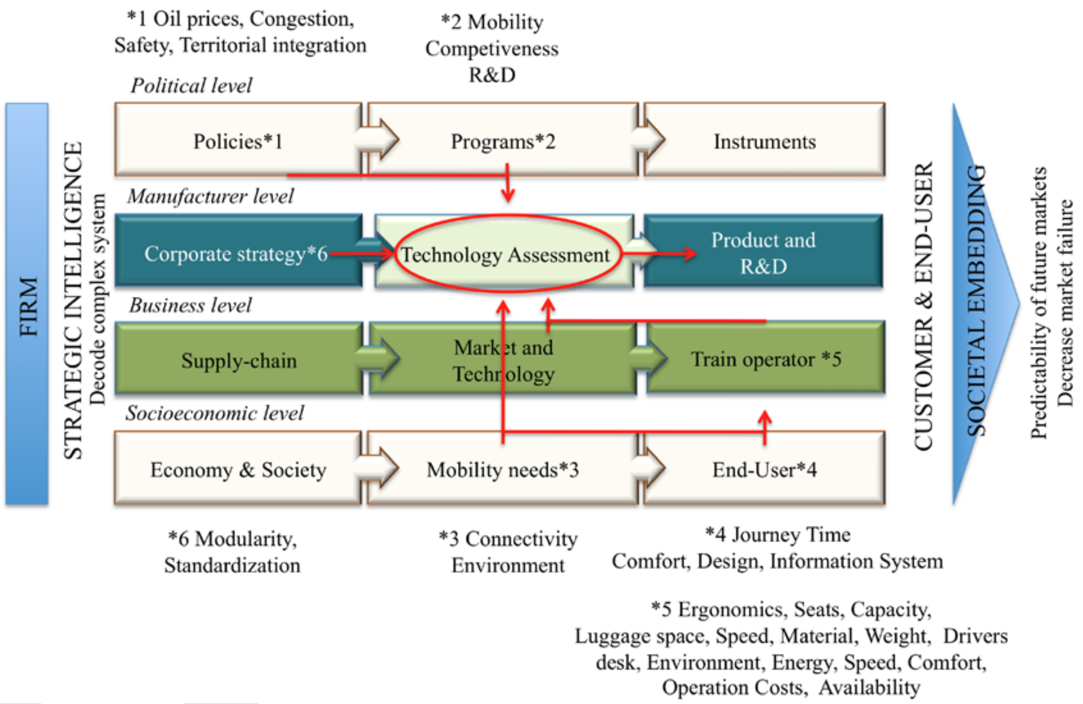

Figure 7: Constructive technology assessment part of strategic-intelligence

As Figure 7 illustrates, constructive technology assessment is found at firm level as a managerial instrument of strategic intelligence, aiming to decode complex innovation systems and functioning as a filter of external constraints – at policy, socio-economic and business levels - to be then considered by top management in the technology development process.

This function is also described in Rip *et al.* [20], as the behaviour of firms towards the "external environment" in which a new product has to survive. Rip identifies three levels of constraints: "business environment", "regulation environment" and "wider society", which correspond roughly to the terminology of Figure 7, as follows: business level constraints, policy level constraints and socioeconomic level constraints.

Continuing with the description of Figure 7, at the policy level (top of the matrix), constructive technology assessment filters governments' policy drivers, such as decreased oil dependency, climate change and territorial integration, as a means to anticipate programmatic and regulatory constraints, (*e.g.* specific norms targeting noise reduction or increased safety of high-speed train vehicles and funding to develop technological solution).

In Figure 7, at the socio-economic level (lower extreme of the matrix), technology assessment aims to decode future mobility trends, in terms of connectivity and environment for instance; and, end-users' expectations, such as journey time, comfort, design, and information system.

At the business level (lower middle part of the matrix), constructive technology assessment filters market and technology constraints and surveys the activity of competitors. At this stage, the manufacturing industry aims to decode the market structure and anticipate clients' technical specifications, such as train capacity and information systems. It is also used to detect new innovation trends within and outside the sector, from component suppliers and knowledge centers, for example.

Finally at the manufacturer level (high middle part of the matrix), constructive technology assessment addresses integrators own constraints, such as corporate strategy, product development and assembly. At this level, technology assessment aims to select all the internal elements that condition technology decision-making, such as cost-reduction, standardization and modularity.

Figure 7 shows constructive technology assessment as the central element at the manufactures level which translates all the external societal constraints as part of a non-linear complex system from the above mentioned levels, which, after consideration from top management, are embedded in the product development process. It functions as an alert mechanism to new policy and normative initiatives, new customer specifications, identification of diversities in actors technology interests and changes in end-users' mobility patterns. It also functions as an instrument to anticipate the socio-economic impacts of technology.

Nevertheless, as Moretto [13] refers, constructive technology assessment is not an institutionalized practice in high-speed train manufacturers; rather, it is practiced on an informal basis by the existing strategic-intelligences' organizational structures and depends on personal engagement, mainly from top management, to be performed.

Knowledge change is yet shadowed by secretive and quite reluctant culture of information sharing that characterizes the railway sector, with constructive technology-type of activities taking only a small share in manufacturing technology development process.

Moreover, the study does not cover technology assessment practices by other stakeholders and their interrelation with the manufacturers. It just focuses on the main OEMs of the high-speed train product.

8 Conclusions

Developing high-speed train technology implies high standards, co-developments and a significant amount of engineering and capital investments. It comprises high-risks, as it consists of a long development cycle contrasting with a rapidly changing complex system. Moreover, the high-speed train has high socio-economic impacts.

To become competitive, the high-speed train manufacturing industry soon understood that it could no longer manage its technology development process on a basis of trial and error, as had happened in the past. The landscape in which manufacturers carry out their technology decisions have changed from a linear to a non-linear complex system of multi-level players.

Participatory type methods resulting in societal embedding of the high-speed train technology development, (identified as constructive technology assessment as argued in Rip *et al.* [7]), became manufacturers' top-management strategic intelligence tool (along with forecasting, foresight, evaluation and road-mapping) to anticipate integration of new technology in the train and markets; to assure admissibility according to regulations; to foresee acceptance by customers and end-users; and surveillance to emerging disruptive technology .

As showcased in this paper, such practices allow for the decoding of the complex system in which technology development and decision-making have to be carried out; increasing the predictability of future technologies and markets; and decreasing market failure of innovative products.

These are the activities held by manufacturers' staff from early product development process in view of aligning technology development with external constraints from policy, socio-economic and business levels, as well as at the internal level from the manufacturers themselves.

Even if yet a minor and an informal practice by the high-speed train manufacturing industry, constructive technology assessment results this way in a balanced learning process, as well a sharing of technology-development responsibility. It places the end-user at the centre of technology development process, while promotes collaboration with the customer, the suppliers and the service providers in design, demonstration and delivery of new technologies.

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