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# Energy savings through innovative and automated freight trains

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**Abstract**

The paper focuses on a particular technology, an intelligent rail wagon. It is a smart wagon characterized by a high level of automation. The wagon is transformed from a passive element into an intelligent element, guaranteeing a reduction in costs and greater management efficiency both at the interchange terminals and on track. The potential energy savings are very interesting.

The main goals of the research are to contribute at enhancement of international knowledge about innovative and automated freight wagons, in the most general framework of researches oriented to the future autonomous freight trains and to illustrate, specifically, the positive impacts in term of energy savings.

*Keywords:* Automated freight train, logistics, simulation, energy saving.

## 1. Introduction

The train is an advantageous and competitive carrier for freight transport compared to road transport, especially over medium and long distances. However, it is characterized by some limitations related to the composition and decomposition in the terminals, to the manoeuvres in the station, to the intermodal exchange operations and to the circulation on the railway line.

Technological processes have favoured the automation of many functions in the field of rail transport. The general interest is to reduce operative management costs, as well as to increase safety, reliability levels and environmental sustainability.

In the last years an increasing interest is addressed to the technologically advanced vehicles with high levels of automation. Some approaches to improve the performance of rail freight transportation have been tested and some first experiences already made in this field (Australia, North America, Europe).

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In specialized literature different levels of automation are identified both in the road vehicles sector (SAE International, 2014; VDA,2015; Keese et al., 2016) and in field of rail transport (Wang et al, 2016; Yin et al., 2017; EuRail, 2019; Ramirez et al., 2022). Figure 1 is born from literature analysis: 6 different levels associated with the development of automation are identified:

- Level 0 – No Automated Driving: the driver is fully responsible for driving;
- Level 1 – Assisted: system assists with speed, braking and steering, while the driver remains fully responsible;
- Level 2 – Partial Automation: driver can hand over to the system in specific applications, but must remain able to take over control again immediately;
- Level 3 – High Automation: system performs driving tasks in defined use cases, but return control to driver beyond defined parameters;
- Level 4 – Full Automation: driver can hand over entire task of driving to the system in specific use case;
- Level 5 – Autonomous driving: system can handle all driving situations without driver.

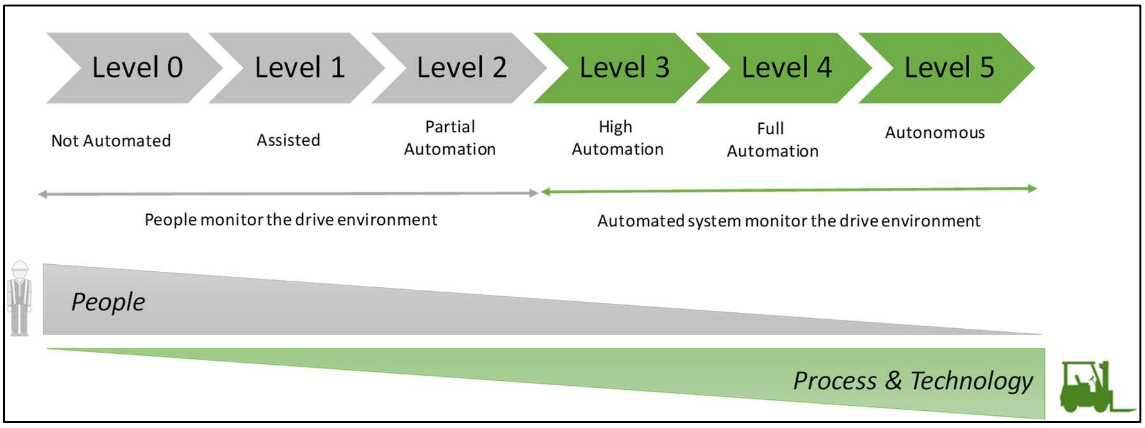


Figure 1: Automation levels

The paper focuses on a particular technology, an intelligent rail wagon called AFW (Automated Freight Wagon). AFW is a smart wagon characterized by a high level of automation. The wagon is transformed from a passive element into an intelligent element, guaranteeing a reduction in costs and greater management efficiency both at the interchange terminals and on track.

The main goal of the research presented in this paper is to contribute at enhancement of international knowledge about innovative and automated freight wagons (Level 2), in the most general framework of researches oriented to the future autonomous freight trains.

Some recent research outcomes, in the rail freight industry and in computer science, are very promising in the supply chain field. The general interest is to reduce operative management costs (less staff components, energy consumption), to increase safety and reliability levels, to reduce negative presence of trucks in the roads (es.pollution impacts), to push the train competitiveness compared with road transport.

The research is part of the activities carried out in the ISTEN project (Integrated and Sustainable Transport in the Efficient Network), funded under the ADRION Community Program aiming to improve the intermodal connections among the maritime ports of the Adriatic-Ionian area and among the ports and their hinterlands.

After an analysis of some international experiences, a general technical description of the AFW is proposed and its running implications in way are illustrated. Therefore, the results of an impact analysis are carried out for a comparison with the traditional system in terms of energetic impacts.

## 2. Towards autonomous freight train. Technological developments

The research on freight train automation can basically be classified into two categories:

- automation technologies aimed at improving train performance;
- autonomous train (driverless).

In the second case, the attention is focused on driving control technologies; the problems are numerous and range from motorization to autonomous driving, from the control system architecture to the aspects of vehicle safety management and the surrounding environment. In both cases, the technological solutions differ according to the type of transport (Figure 2).

Freights can be moved by rail using two different types of transport: single wagon or shuttle train. Single wagon transport bases its strength on the presence of an intermediate sorting plant within the transport chain. Between the origin and the destination, the railway wagon can travel on different trains in order to optimize its circulation both from the productive and economic point of view. The most suitable transports for this typology are those to low frequency or that have a seasonality. Instead, a shuttle train is a freight train that travels from the loading point to the unloading point without intermediate stops; in this case we speak of a point-to-point traction service.

For single wagon transport, research is moving towards the construction of automatic railway wagons, while in the logic of shuttle train, transport experiences have already been carried out with automated and autonomous locomotives.

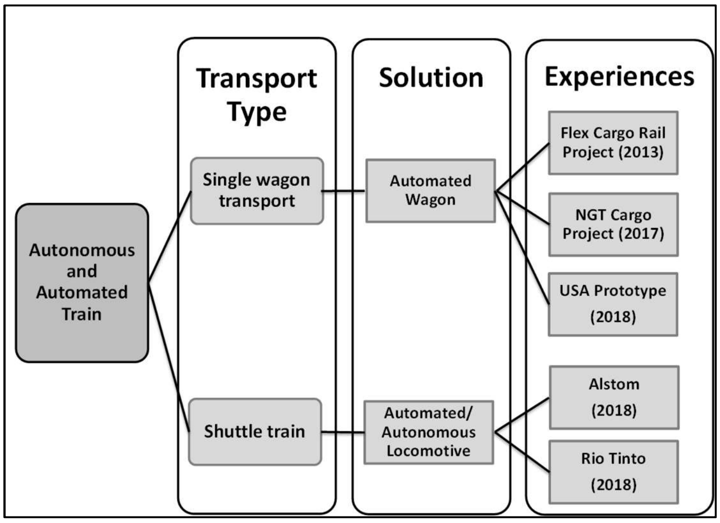


Figure 2: Automated railway transport

The FlexCargoRail system focuses on electrical powered, radio controlled freight wagons to raise movement flexibility of the wagons for shunting operations and to grow efficiency of the single wagon load traffic. The single waggons are self- electrically propelled and are operated via radio remote control by personnel in the yard. FlexCargoRail (Dickenbrock et al. 2009; Jeschke, 2011) is not an autonomously driven and self-organising rail freight waggon system. The idea is to accelerate the shunting processes and to bring in more flexibility. As each FlexCargoRail waggon is equipped with an electric drivetrain and a battery, distributed traction for freight trains - as already applied to modern passenger trains – could be a future extension of the system. Unlike the initial situation in which all waggons have to be pulled by a locomotive, the main advantage of FlexCargoRail is that every single payload carrier equipped with FlexCargoRail technology can be moved independently from the switcher/locomotive during shunting (Figure 3).

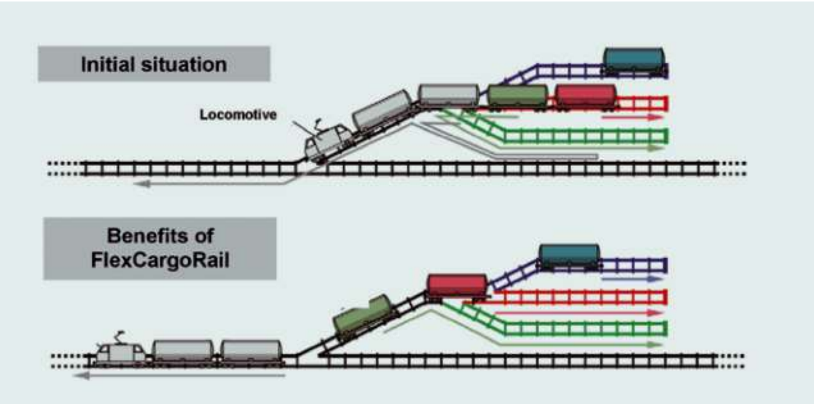


Figure 3: Benefit of FlexCargoRail
Source: Dickenbrock et al. 2009

A concept for the next-generation transport of cargo by rail— NGT CARGO—is proposed by German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt-DLR, 2017; Himmelstein, 2017; Malzacher et al., 2018 ) to broaden the market share of European rail freight. Combining a high level of automation, intelligent handling and high speeds should render rail freight transportation more flexible and increase system capacity. Currently, an elaborate process using rigid operating procedures underlies single wagon transport. Coupling and uncoupling wagons, picking them up and delivering them is very time- and resource-intensive and accounts for 30-40 percent of overall costs. Manual coupling processes lead to long idle periods for individual wagons and an average system speed of just 18 km/h for single-wagon transport. A lead time of approximately five days is required to make the personnel, material and routes available. Intelligent freight wagons in the NGT CARGO concept have a separate drive based on electric motors and a battery that stores energy recovered during braking. Single wagons shunt autonomously, without the need for staff, locomotives or overhead lines. Each wagon is equipped with sensors that enable travel of the last kilometers to the respective customer automatically and autonomously. The wagons can also be driven directly into ports, transhipment stations or logistics terminals, right up to the high level racks, where they are also loaded or unloaded automatically. For operation at high speeds, the NGT CARGO single wagons form a unit and are combined with one or two end cars, which provide the necessary drive. With the appropriate infrastructure, up to 400 km/h is conceivable. Speeds of up to 160 or 200 km/h are attainable on existing lines.

Meanwhile, tests have been operated in Europe and Australia to assess the possibility of freight trains driven by an autonomous and automated locomotive. In 2012 TU Dresden - Institute of Railway System, Public and Urban Transport and TU Berlin - Rail Vehicles Department published "White paper Innovative rail freight wagon 2030" (König and Hecht, 2012). The paper represents a collection of proposal for coordinated implementation and for further developments of innovative freight rail wagon. The central idea consists on overall technical and operational concept for the design and use of rail freight wagon. The paper refers to the “5L future initiative” as the basis for the new growth in rail freight transport.

This initiative creates a framework for five growth factors that have been identified for successful introduction of the innovative freight wagon: low noise, light weight, long running, logistic capable, LCC oriented (Life Cycle Costing). These factors include the following essential properties:

- low noise: reduction of noise emissions;
- light weight: higher payload, less net mass;
- long running: reduction of downtimes and unproductive times, increases average annual mileage, higher reliability;
- logistics capable: possibility of integration into supply chain, service quality better then/equal to road and air transport;
- LCC oriented: integration of LCC oriented components, with procurement costs rapidly amortised over product lifetime and more than compensate for by cost reduction in operation and maintenance.

An autonomous freight train was tested in the Netherlands by the railway engineering Alstom in November 2018 (van Gompel, 2018). The prototype of the train travelled for about 100 km without driver. Automation allows the driver to focus on supervising train progress. The purpose of the test was to provide a live demonstration that the train and the signal system can communicate effectively to guide the train. Alstom has signed an agreement with the Dutch infrastructure operator ProRail and Rotterdam Rail Feeding (RRF) to carry out the test along the Betuweroute, a 150 km double-track railway line that connects Rotterdam to Germany. The experimentation has been made with a freight train BR203. The tests concerned the Automatic Operation of the Train (ATO), where the automation level 2 was tested. The train operates completely autonomously in level 4. This will not happen in the Netherlands in the short term. The trains equipped with ATO can operate at closer intervals, which increases the capacity of the railway network and allows for reduced energy consumption, because trains operate more uniformly. Automated operation can therefore be an added value for operators facing increasing traffic on the current railway networks without making expensive changes to the infrastructure.

In Australia, on July 2018 a freight train, hauled by three locomotives and carrying around 28.000 tons of iron, travelled more than 280 km from Rio Tinto’s Tom Price mine to the port of Cape Lambert without a driver in the cab (Railway Gazette International, 2019). It was monitored remotely by operators from Rio Tinto’s Operations Centre in Perth more than 1500 km away. The cost of Rio Tinto’s AutoHaul operation (Ansaldo STS, 2018) of heavy-haul trains in Australia’s Pilbara region exceeds $900 million.

In 2018 the DB Cargo/VTG started with tests on new wagon types. The research project "Development and testing of innovative freight wagons" has been subsidized by Germany's Federal Ministry of Transport. The innovations range from the use of lightweight components to energy savings and noise reduction, from customized wagon adjustments to accommodate freight to new digital modules that optimize freight wagon handling.

There is still much to do in this field and it is necessary to proceed gradually. The progress also moves through applications of advanced technologies relating to some components of freight train. Some research are aimed at improving the train performance by means of automation and they appear promising.

Currently studies of pre-engineering are in progress towards the automation of the wagon (self-propelled drive, predictive maintenance, self-contained auxiliary power, technical specifications of the control algorithm). A specific attention is addressed here to an innovative freight wagon mainly based on a specific technology related to railway bogies.

## 3. An innovative automated wagon: ACTIAX

An intelligent rail wagon, called AFW (Automated Freight Wagon), is here briefly presented. AFW is a smart wagon characterized by a high level of automation. The wagon is transformed from a passive element into an intelligent autonomous element.

The research has initially been addressed on the railway bogies (Actiax by Serise Technologies). Actiax makes the railroad car an active element of the train consists: it includes a battery to store energy, a converter, an electric motor, and a controller. Independently and in a totally safe manner, it applies the optimal traction/braking effort to the axle and assists the movement of the train.

This system adds traction power and regenerative braking capacity to currently under-utilized freight trains truck axles, and provides them with the benefits of distributed traction so widely used on passenger trains: savings on fuel and energy up to 30% depending on train configuration and track profile, and reduction of green-house gases emissions; complementary electric braking, reducing wear of mechanical brakes and increasing safety by automatic electric brake application in case of overspeed. Distributed traction power along the train provides, among other benefits, a better overall track adherence.

Actiax is designed to be installed on existing conventional wagons, when other approaches require to entirely redesign the freight wagon itself (as in NGT Cargo concept). It is an add-on system that enables a conventional freight wagon to be "upgraded" into an intelligent active semi-autonomous wagon. Moreover, a train consist comprising both conventional and Actiax equipped wagons, can be run without any specific condition. Actiax is not by itself the autonomous train: it is a device that can be rather simply installed during maintenance activities on a conventional wagon and turn it into an automated one (AFW).

For now, freight train wagons are being pulled by locomotives. But they could play a more active role and generate energy savings, by using an independent traction module for bogie, under the railway vehicle. How? By recovering the kinetic energy produced by the bogie during braking. In traditional mechanical systems, this energy is lost because it dissipates into heat. Actiax system turns it into electricity and stores it in a lithium-ion battery that then drives a traction effort if the train accelerates or climbs a slope. Recovery of the energy generated by braking in a battery is not new. Electric and hybrid vehicles operate on this principle. On the other hand, no comparable system exists to independently manage energy on a single train car.

No need to look far to find most of the necessary components: the size and power of motors, converters and batteries developed for electric cars suit the needs of a bogie. Simply adapt them to the bogie, add an electronic controller and attach them to various sensors to identify the speed, slope, acceleration and pressure recorded by the axles.

Using this information, Actiax autonomously selects the appropriate mode to provide assistance to the locomotive without external power. There is no question of having a system with a communication cable or radio communication between the locomotive and the car. The reason is simple: freight cars are unhooked from a train consist and then coupled to another on several occasions during the same trip. Installing the system on half of the cars of a consist would reduce the fuel consumption of a locomotive by up to 30%. Currently, rail freight alone generates more than 7 million tons of $CO_2$ per year in Canada, according to Environment Canada characteristics.

The system would still benefit the railroad cars owners' companies. The battery would be enough to move within a shunt yard without the use of a locomotive or gravity going downhill (hump shunting). In the case of a refrigerated wagon, it would provide permanent cooling power.

Independent control of the bogie would also improve safety. The module can activate the brakes when it detects an abnormally high speed, so as to prevent events similar to the 2013 railway tragedy in Lac-Mégantic in Quebec. The context today seems favourable. The price of lithium-ion batteries, the most expensive component, is constantly falling; it could drop below 100 $/KWh by 2020 and makes the product more affordable than expected. There remains a rather conservative market. It's a concept that breaks all the habits of the industry.

### *3.1 Reduction of fuel consumption and GHG emission*

Hybridation is making reference to hybrid EV in the automotive industry: it actually makes use of regenerative power (deceleration and downhill operation) and supplemental traction effort (acceleration and flat or uphill operation). It is achieved by the usual components: electric battery, electric drive, and drive controller, all of them very similar in size and characteristics to the ones currently widely used in the EV industry; to which is added a specific drive to axle gear (Figure 4). Fuel economy and GHG emission reduction is obtained by collecting part of the energy that is lost in heat and brake pad wear on conventional trains in mechanical brakes: depending on track profile, train trip and quantity of wagons equipped in the train consist, fuel economy of up to 30 is achievable: all without having to change train operation mode as each Actiax system controller senses train movement and smoothly locally adds tractive or braking power as impulsed by the train locomotive.

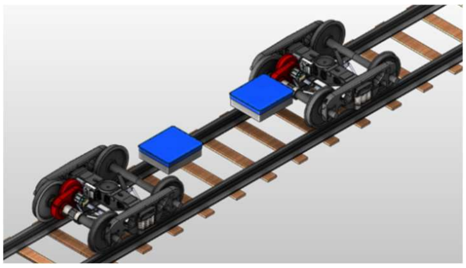

Figure 3: Actiax Trolley

### *3.2 Overspeed protection.*

An additional Actiax benefit of adding electric braking capacity on the AFW is the possibility of rheostatic electric braking when speed is over a pre-programmed set limit linked to location and direction of movement: this feature can be of great help to prevent train overspeed and to slow down "mad trains" running downhill with no mechanical brake applied, and to increase railway safety.

*3.3 Distributed traction*

75% -95% axles (that is, all axles but the locomotive ones) in a conventional freight train are not put to use for traction or regenerative braking, as it is the case in most modern passenger trains. Actiax is installed on wagons distributed throughout the train consist and applies by itself traction or electric braking power when required: acceleration and deceleration rates can be greatly increased and regeneration braking can be used. Automatic distributed traction also reduces train slack and brake pads wear (up to 40% of electric braking).

*3.4 Self-propelled drive*

Traction force and power enabling short distance self-propelled low-speed movement is a key feature of the AFW equipped with Actiax. It thus can be remote-controlled in a yard, reduces the need for a shunting-yard locomotive, to make shunting much more efficient (Figure 5).

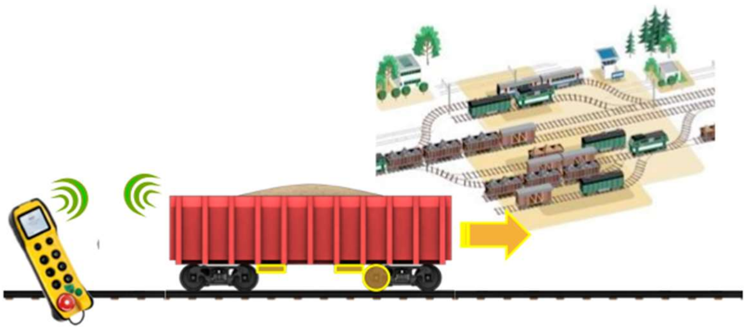

Figure 5: Remote Control

*3.5 Predictive maintenance*

The AFW has a smart controller embedded in Actiax, that includes a GPS, an acceleration sensor, and all industry standard communication devices (Wifi, 4G, IoT, etc.). Using and analysing the data collected during train movement, each AFW can record and report track defects, flat wheel detection, as well as wagon location. A statistical analysis of track defects based on recurrent detections from all AFW in the train as well as other trains can be of great used to help predicting maintenance needs (Figure 6).

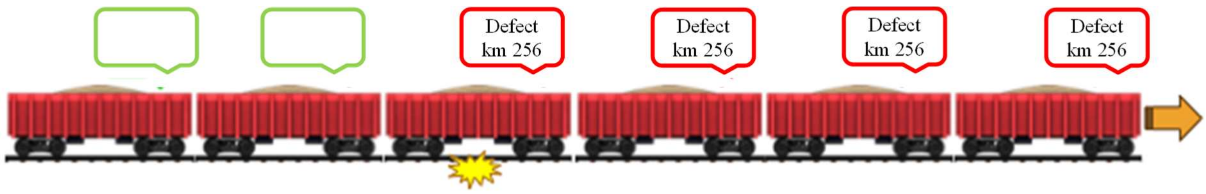


Figure 6: Detection and transmission of defects

*3.6 Self-contained auxiliary power*

Valuable self-regulated electric energy capacity (10 to 50 kWh) is available in Actiax battery (Figure 7), on the wagon itself. It is permanent (no need to change batteries) and requires no train cable. It is a dependable on-board source of power for air conditioning, compressor, refrigeration, reefers, as well as on-board electronics like hot box monitoring, ECP brake controller, ID devices, etc.

Figure 7: Actiax battery

*3.7 Actiax features*

A key aspect is that there is no need for a train control line from the locomotive to the AFW: Actiax embedded electronic controller monitors speed, acceleration, grade, location and direction and selects traction or braking based on an algorithm, all while protecting the ability of the locomotive to safely keep full control of the train movement. This allows the AFW to be seamlessly inserted in any train at any time, and to be immediately effective even if coupled to conventional wagons.

The weight of the system ranges from 250 kg to 450 kg (unsprung weight: 50 kg, motor and gear) according to the size of the battery, with a power pack capacity customized to requirements and clearance, starting from 10 kWh to 70+ kWh.  The electric motor is rated at 37 kW nominal and kW maximal power. All components are designed for harsh environment.

*3.8 Economic value*

The multiple features of Actiax enable a full combination of benefits customized to the operating strategy of the AFW in the train. They provide an interesting return on investment, including 5% to 30% fuel savings, reduced wheel and brake wear, increased safety, self-propelled shunting, dependable on-board power for various needs, and monitoring and predictive maintenance capacity.

## 4. Simulation approach for impact assessments of AFW

The simulation allows to dynamically reproduce a system behaviour through the representation of its components and related interactions in terms of functional relationships using mathematical and logical models. Through the simulation it is possible both to obtain significant indicators useful for measuring performance, and to analyse effects produced by changes in configuration and set-up.

The objective of the simulation for the assessments of the use of AFW equipped with Actiax technology is to compare the operational costs of a train including AFW to the ones using conventional wagons. It is important to note that the multiple benefits of the various new features brought by using Actiax on wagons can all be simulated, but that it actually consists in a combination of different simulations using different approaches:

1. *fuel savings and GHG emission reduction*: simulation of fuel consumption along a specific track;
2. *periodic maintenance savings*: computing of brake pad and wheel wear reduction and add maintenance for Actiax components;
3. *predictive maintenance savings*: evaluation of benefits of earlier and widely spread detection of track and axles defects by wagons themselves, without the need for special equipment;

4. *train operation savings*: evaluation of benefits of additional available traction power distributed throughout the train, for example the ability to accelerate faster or to climb steeper grades without the need for an additional locomotive;
5. *yard operation savings*: simulation of yard operation having AFW moving by themselves to assemble/disassemble train – reduction of yard locomotive use and shunting process speed-up;
6. *special wagons operation savings*: evaluation of the benefits of having reefer wagons and containers refrigerators being electrically powered rather than fuel powered during train movement and operation;
7. *safety and accidents prevention*: estimation of cost accidents of over-speed and mad train accidents by using statistics of such events and their impacts.

Each item of the above list requires a different simulation/calculation approach, in terms of modelling and input parameters.

The simulation approach adopted to evaluate the benefits of the new technology, the high-level AFW Actiax automation wagon, with reference to item 1 and the results of a pre-study in a European railway line context are described below. Other benefits will have to be evaluated based on operation modes parameters and specificities of the train operating company, then summed-up to obtain a complete LCC evaluation and cost/benefits analysis.

### *4.1 Simulation approach*

Figure 8 shows the procedure followed for the simulation of energy savings obtained with the use of Actiax technology compared to a conventional freight train.

By calculating at each position along the track the energy needed to get the train up to a predefined speed (kinetic energy), the energy required to move the train to a specific altitude (potential energy), and the energy collected by regeneration by the Actiax systems in the train, a comparison of the energy consumption of both trains is done.

The input parameters for the simulation are: maximum traction power, traction drive efficiency, maximum braking power, braking efficiency, set speed along track, track characteristics, maximum/minimum battery charge, mechanical/electrical braking power ratio.

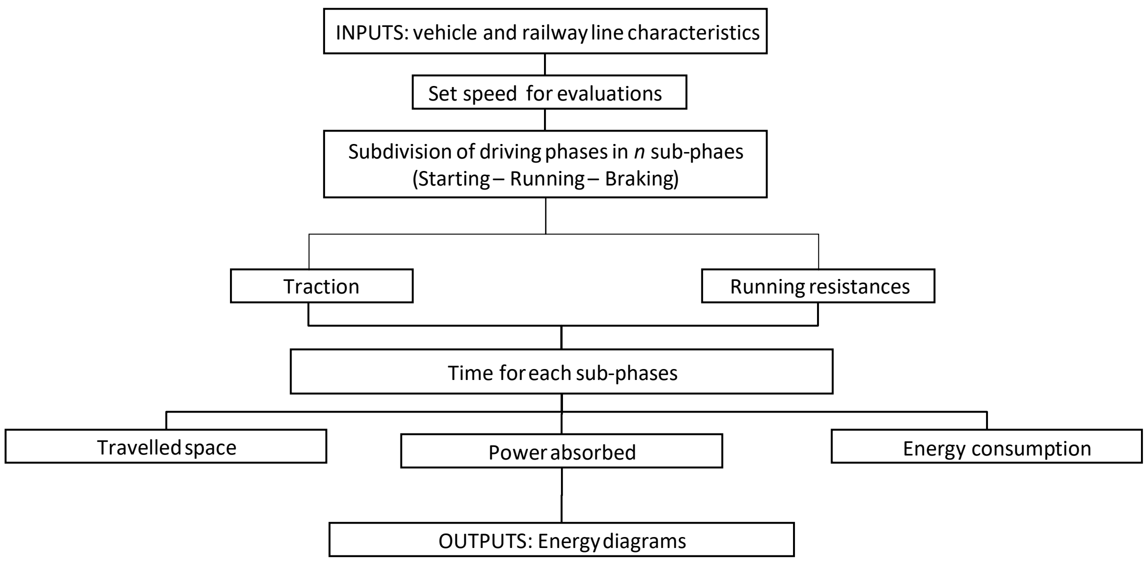


Figure 8: Simulation process flow chart

Regarding to the speed set for evaluations, it should be noted that in varied motion the speed changes according to the characteristics of the propulsion system (mechanical traction characteristic) or braking and to motion resistances.

If the characteristics of the railway are homogeneous, the motion between two successive stops can be broken down into phases. In each phase the speed can be described by a continuous function; the following phases are identified:

- *starting phase:* the speed increases continuously, the jerking is infinite. The analytical equations for the evaluation of maximum acceleration ($a_m$), speed ($v$) and space ($s$) are

  $a_m = cost$

  $v = a_m \cdot t$

  $s = \int_0^t v dt = \int_0^t a_m \cdot t dt$

- *running phase:* in this phase, between times $t_1$ and $t_2$, the speed ($v_r$) is constant, the motion is uniform; so:

  $a_m = 0$

  $v = v_r$

  $s_2 = s_1 + v_r \cdot (t_2 - t_1)$

- *inertial running phase*: the speed is reduced due to the resistance to motion; the vehicle is not subjected to tensile stress or braking;
- *braking phase:* the speed varies continuously from the steady-state value to the null value. The equations of motion are similar to those seen for the starting phase; the speed variation is considered positive when it is a reduction. Therefore, we have:

  $a_m = a'_m$

  $v = v_m - a'_m \cdot (t - t_2)$

  $s - s_2 = \int_{t_2}^t v dt = \int_{t_2}^t v_m dt - \int_{t_2}^t a'_m \cdot (t - t_2) dt$

If the maximum speed changes, for example in the case of longitudinal slope increases, there would be further phases of varied motion between successive regime phases.

The presence of curvatures of the layout in plan along the railway path imposes speed limits. In fact, the centrifugal force acts transversely to the direction of travel and alters the distribution of the reactions to the wheel-rail contact. The speed limit in curves ($v_c$) can be evaluated using the following expression (Figure 9):

$$v_c = [g \cdot R \cdot (c + d \cdot h/s)/(d - c \cdot h/s]^{1/2}$$

where $g$ is the gravity acceleration and $R$ the curve radius.

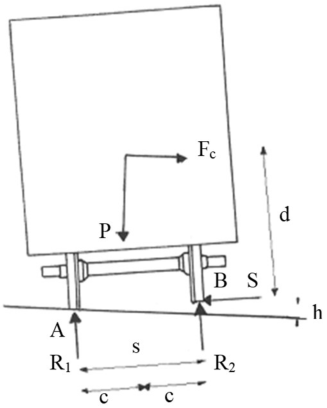


Figure 9: Scheme for the evaluation of the maximum speed in curves

The traction effort is a function of the medium speed in a considered time interval ($\overline{v_i}$) and it can be evaluated by using the following expression:

$$T(\overline{v_i}) = R_t(\overline{v_i}) \cdot (W_{pull} + W_{driving}) + \beta \cdot a_i \cdot (W_{pull} + W_{driving})/g$$

where: $R_t$ is the rolling resistance, $W_{pull}$ is the pull weight, $W_{driving}$ is the driving weight, $a_i$ is the acceleration in time interval $i$.

Rolling resistance formula (also known as Davis formula) of the whole train, time accounts for the unitary resistance of each locomotive and wagons of the number of axles. The numerical values in the formula vary according to the type of train considered: passenger, freight, type of cars, etc.

$$R_t = (1{,}3 \cdot W \cdot n + 29 \cdot n) + b \cdot W \cdot n \cdot v + C \cdot A \cdot v^2 + 20 \cdot W \cdot n \cdot G$$

where:
- $v$ = speed (mph);
- $W$ = weight per axle (tons);
- $n$ = number of axles;
- $b$ = coefficient of moving friction;
- $C$ = drag coefficient of air;
- $A$ = cross sectional area of vehicle;
- $G$ = % grade (upgrade +, downgrade -).

The energy consumption (E) can be calculated using the following expression:

$$E = \int_0^t T(v) \cdot v dt$$

where $T$ is the traction effort and $v$ is the speed.

This expression takes on different connotations depending on the phase of the motion (starting, running, braking). Accurate quantification of consumption is not easy due to the many factors that affect it; a particular effect is to be attributed to the irregularity of movement, or to the phases of varied motion that occur with the same path.

The use of rolling resistance, traction effort and speed along the track enables the calculation of instantaneous power in both the locomotive and the AFW, which is incrementally integrated over time to obtain energy consumption.

*4.2 Application*

The results obtained during a pre-study carried out in a European country in order to test the advantages (in terms of energy saving) deriving from the use of the Actiax prototype are proposed below. The study was carried out on a 450 km long railway line; the height profile of the line is shown in figure 10. The path followed by the freight train reaches a maximum altitude of 350 m and is characterized by slopes (about 7‰) especially in the terminal section.

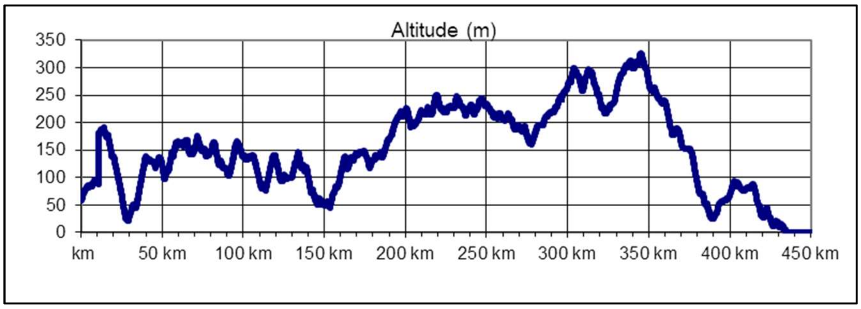


Figure 10: Altitude profile of railway path

Figure 11 shows the train speed trend. A maximum speed of about 40 miles/h can be observed, the train stops for the first time after covering about 200 km from the start station, the second stop occurs at km 300 and then the train makes slowdowns about every 50 km.

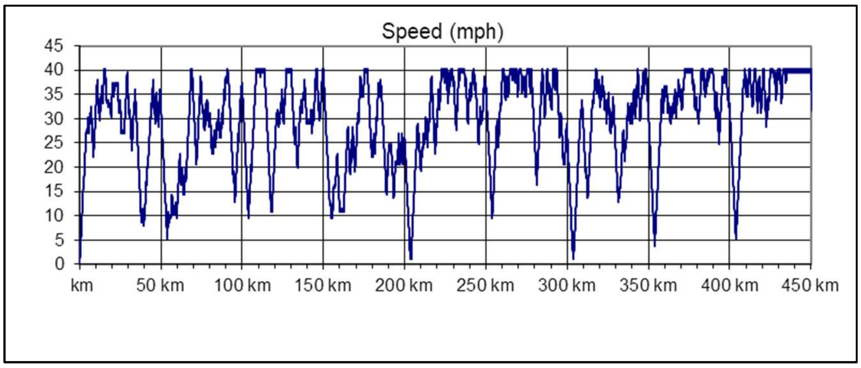


Figure 11: Speed trend

Figures 12 and 13 respectively show the energy consumption recorded for a conventional freight train and for a freight train equipped with Actiax technology.

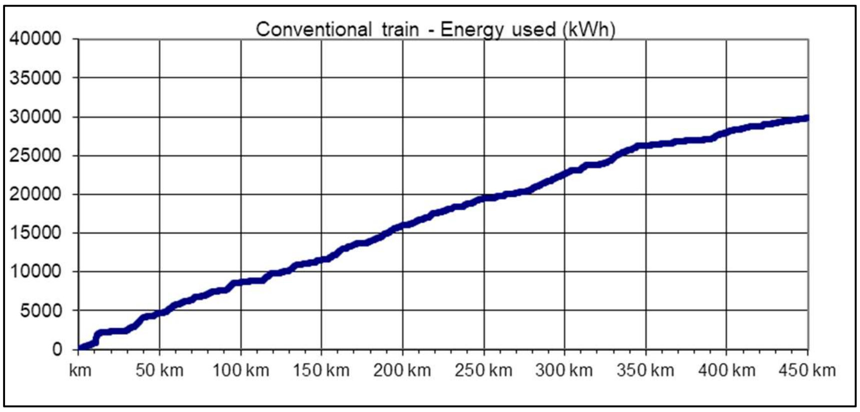


Figure 12: Energy consumption trend for conventional train

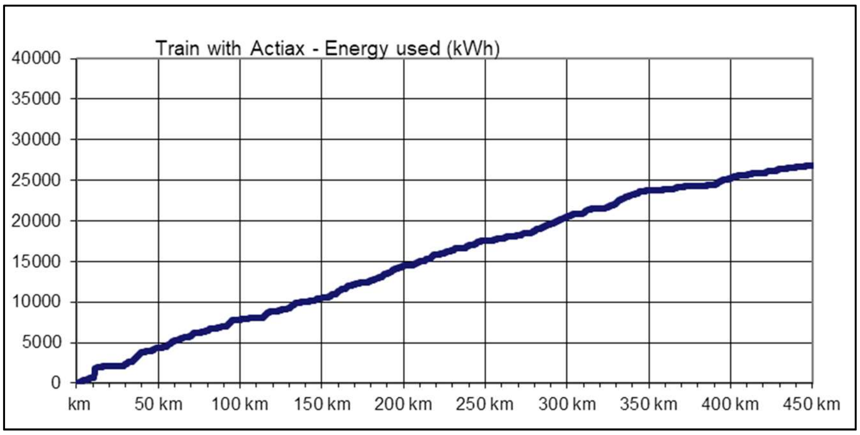


Figure 13: Energy consumption trend for train equipped with ACTIAX

The evaluations were carried out assuming the following values for the parameters in the rolling resistance:

- $b =$ coefficient of moving friction (0,03 locomotives and 0,045 freight cars);
- $C =$ drag coefficient of air (0,0017 streamlined locomotives, 0,0025 other locomotives, 0,0005 for trailing freight cars);
- $A =$ cross sectional area of vehicle (120 sq. ft. for locomotives, 90 sq. ft. for freight cars and 120 sq. ft. for passenger cars).

The results can be displayed, in a synoptic framework, by curves that illustrate the difference in energy required, as shown in Figure 14. The two curves starting at zero on the left show the energy along the distance, the bold green line for the Actiax equipped train, the twin red line for a conventional train. The other curves (dark blue) shows the altitude level along the track.

In the simulation displayed below, it can be seen that the total energy used by a conventional train at arrival location amounts to 29409 kWh, while the energy used by the Actiax equipped train is 26496 kWh : energy savings of 10% are achieved.

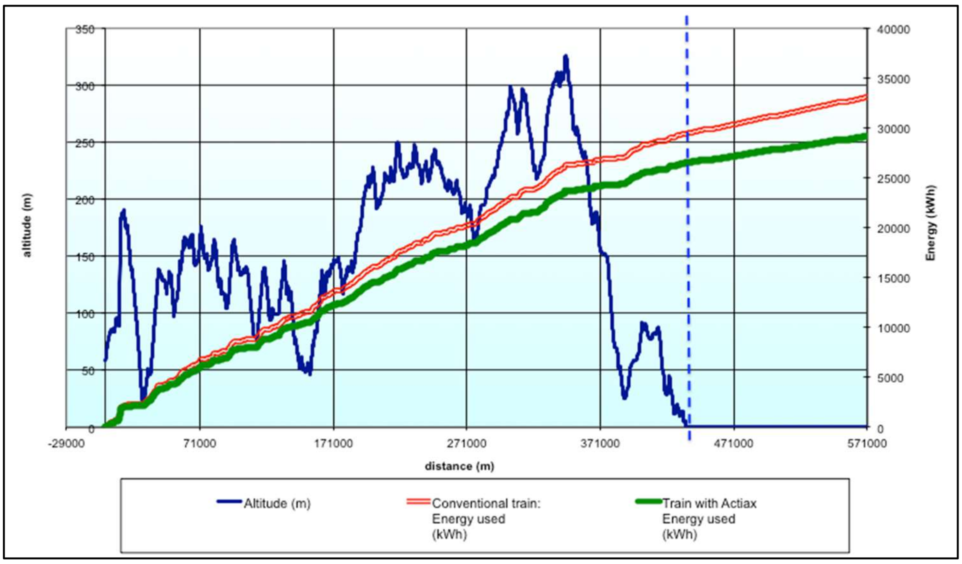


Figure 14: Energy and travel profile

## 5. Conclusion

Technological processes have favored the automation of many functions in the field of rail transport. The general interest is to reduce operative management costs (less personnel components), as well as to increase safety, reliability levels and environmental sustainability. In some cases, for the reserved and protected railway, there are driverless systems, autonomous metro lines in the world. The paper proposes a simulation analysis for the comparison between a conventional freight train and a freight train equipped with Actiax technology. This technology contributes to the creation of an intelligent railway wagon characterized by a high level of automation able to guarantee a reduction in consumption, operating costs and travel times. The first results, related to a pre-study, demonstrate the advantages deriving from the use of the new technology in terms of energy savings.

Other promising future developments of research are envisaged:

- definition of models and procedures for the evaluation of the impacts generated in terms of periodic maintenance savings, predictive maintenance savings, train operation savings, special wagons operation savings, safety and accidents prevention;
- evaluation of operating costs;
- a model describing the global impact (including time and monetary costs) generated by new Actiax technology.

Another research field concerns the application of AFW inside the railway terminals. The train composition for the routing involves shunting which often occupy significant times. Shunting describes the movement of wagons – as single wagons, train consists – within a yard or between a yard and a place in proximity to the yard. Shunting is almost always necessary to spot and pick up wagons to and from their loading/unloading positions and to consolidate and deconsolidate trains.

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