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An Auxiliary Tool for Choosing a Drive for Selected Areas of Transport

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Abstract

The global transport sector is standing at the crossroads of innovation with an urgent need for sustainable solutions that drive transformative change. With its exceptional energy density and ecological footprint, hydrogen has proven to be a pioneer in the race toward greener transportation alternatives. Ambitious decarbonization targets and rising carbon dioxide prices are forcing society to look for new ways of production, and hydrogen can play a key role in revolutionizing not only transport but also the transition from fossil fuels to cleaner energy sources. This revolutionary element offers solutions for ecological, energy, and economic challenges that the world is currently facing, and its use in transport is becoming more promising.
As a producer of emissions, the railway sector plays a large role in greenhouse gas emissions and contributes significantly to the worsening of the climate situation, especially in the vicinity of non-electrified lines. In order to improve the status of this problem, efforts must be made to research and implement alternative energy sources. In an effort to improve the infrastructure, drives with alternative fuels are deployed around the world. Alternative fuels have different energy requirements, depending on the type of drive in which the energy is generated for a given vehicle. Choosing the right drive and fuel is a difficult question that requires dealing with various aspects and variables that enter as decisive parameters when choosing a low-emission or no-emission drive method.

Keywords: alternative fuels, decarbonization, fuel tank safety, navigation systems

1. Introduction

Trends in Transport—The Fuel of the Future: The trends in transport regarding the fuel of the future are currently very unpredictable, and the solution to this issue is still unclear. While choosing a suitable drive or fuel, it turns out to be inevitable to consider economic aspects, environmental aspects, and of course, it is important to take into account the level of risk at an acceptable level with regard to the technology used. Transportation is an inseparable part of the modern world and faces an urgent challenge – finding sustainable solutions that maintain its functionality while protecting the environment. When we refer to transportation, we encompass all forms of conveyance used for the movement of people and goods. In Slovakia, transportation contributes significantly to greenhouse gas emissions, accounting for 21.15% of the total amount, with railway transport alone responsible for 0.23%, equating to 82,149 tons of CO2 annually according to SHMU air quality division (OEAB, n.d.).

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On a global scale, the transportation sector stands at a pivotal crossroads, presenting multiple potential solutions. Both the Slovak Republic and the European Union are committed to improving the quality and accessibility of public personal transportation within our region. As members of the European Union, we have pledged to achieve carbon neutrality by 2050 (Linklaters, n.d.). Meeting this ambitious goal requires substantial efforts to transition to a climate-neutral economy, with significant changes particularly needed in the transportation sector. Enhancing the role of public personal transportation in society is a primary focus (European Commission, 2019).

Undertaking a transformation of this magnitude necessitates meticulous preparation. Choosing an appropriate propulsion system for non-electrified tracks involves precise geomorphological mapping of the track locations. Following this mapping, we can utilize progressive methods to select suitable propulsion systems and determine the optimal layout and placement of refueling or charging stations (Esfandiyar et al., 2023).

The entire process of determining track parameters hinges on carefully selecting measuring equipment capable of recording the operating conditions on individual tracks. This data is crucial for selecting a suitable alternative propulsion system to replace diesel engine units. The collected data will not only inform future procurement of alternative propulsion systems but will also serve various purposes, including training personnel in the operation of rail vehicles (Molęda et al., 2023).

2. Methodology

The importance of knowledge - each journey consists of three basic phases. The first phase of the journey between stops is acceleration, in this case, the acceleration during starting-up. The second phase, ideally, is steady speed and, therefore, the maximum permitted speed on a given track section. The third phase is deceleration, negative acceleration, or braking (Olofsson et al., 2005). To create a track model and determine the performance parameters of the track, it is important to find more specific track parameters. GPS coordinates measured with great accuracy are needed for the track conditions, which describe the track as such (Vale & Simões, 2022). During the journey of a rail vehicle on certain track sections, there may be GPS signal interruptions due to insufficient coverage or obstructing obstacles, such as tunnels. In the case of GPS signal failure, the position is calculated from the inertial measurement unit (GPS.gov., 2022).

For the needs of Železničná spoločnosť Slovensko, a.s. (Slovak Railway Company) to evaluate the energy consumption of railway tracks, it is necessary to have a specific recording device capable of recording the required parameters. Of course, the requirements of the device were not only recording specific data but also a robust construction and simple operation with a sufficiently large battery capacity.

An important task was to choose a suitable location to place the device on the vehicle. The device was placed in a pre-selected location in the driver's cabin to avoid interference with other devices installed on the vehicle (see Figure 1). At the same time, it was a condition for possible placement options that the device did not disturb the driver during work.

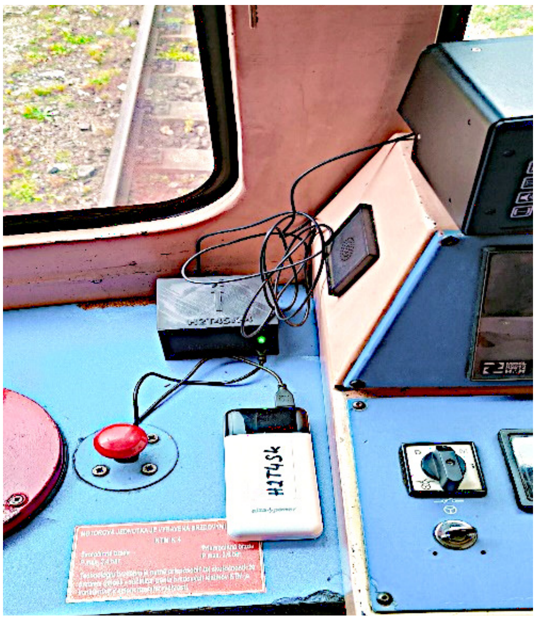

Figure 1. Example of the location of the measuring device in the driver's compartment. The authors's own material.

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Required measurement parameters:

Measurement of accelerations using a uniaxial accelerometer:

1. Accelerometer type: MEMS
2. Measurement range: ± 2 g
3. Minimum measurement frequency: 100 Hz
4. Resolution: 0.1 mg_{rms}
5. Noise: 0.07 mg_{rms}
6. Maximum embedding axis error: 30 mrad

Measurement of position and velocity using a GNSS (Global Navigation Satellite System) receiver:

1. Position and velocity measurement with a minimum frequency of 10 Hz
2. Support for simultaneous reception of signals from navigation systems: GPS, GLONASS, Galileo, BeiDou, SBAS – EGNOS
3. Support for reception at a minimum: frequencies of L1 and L2 GNSS systems
4. Ability to receive RTK corrections
5. Position accuracy with SBAS: ± 1.0 m
6. Position accuracy with RTK: 0.01 m + 1ppm
7. Velocity accuracy: ± 0.05 $m.s^{-1}$
8. Position determination speed after device start-up:
   - Cold start: 25 s
   - Hot start: 2 s

Parameters of the device for sampling and storing measured signals:

1. AD converter: 24 bit
2. Measurement accuracy at (0-40°C) max ± (0.04% of the measured value + offset)
3. Maximum offset: 40µV
4. Minimum sampling frequency: 100 Hz
5. Minimum memory: 16 GB

3. Device selection

Looking at the given requirements, this should be an advanced combined sensor incorporating a MEMS accelerometer, which allows acceleration measurements, and a GNSS receiver to measure position and velocity.

In this regard, it may be a very accurate Inertial Measurement Unit and a correspondingly strong GNSS receiver capable of operating with several navigation systems simultaneously, such as GPS, GLONASS, Galileo, and BeiDou, while receiving RTK corrections for improving position accuracy. Such devices find applications in geodesy, navigation, Geographic Information Systems, etc. Furthermore, integrating all these sensors into such devices can provide highly accurate information in real-time on acceleration, position, and velocity (Introduction to GNSS IMU Systems, 2023).

With the vehicle orientation known, these specific forces measured by the accelerometers transform from the body frame into the navigation frame. However, the latter includes specific forces that have the effect of gravity in them. In this regard, gravitational acceleration has to be subtracted to get the actual acceleration of the vehicle. This, therefore, makes the system consider only a net acceleration due to the motion of the vehicle (La Scaleia et al., 2019).

Error accumulates with time in INS systems, specifically strapdown systems, due to sensor noise, bias, and drift. The issue is of interest because even very tiny errors are increasing rapidly, resulting in inaccurate navigation data. To alleviate this fact, INS is often combined with other sensors, such as GPS, barometers, and magnetometers. Additional sources provide periodic corrections and ensure long-term accuracy. The hybrid approach, often referred to as the integrated INS/GPS system, capitalizes on the strengths of each technology to overcome their respective weaknesses (Rudyk et al., 2020).

The advantages of strapdown inertial navigation systems are that there are no moving parts; thus, it makes for a more robust system and is less prone to the failure of mechanics compared to a gimballed system. In return, this imposes a much higher computational burden due to the complex transformations and continuous integration involved. However, these challenges are manageable today, with enhanced computing capabilities (Zhang, 2018).

The inertial navigation system is able to measure the position and motion due to an interesting interplay of precise sensors, rigorous mathematical treatment, and continuous error correction. Such systems are a sine qua non in modern navigation, providing reliable and accurate data vital for the safe and efficient movement of vehicles around the world.

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The major advantages of strapdown systems are that there may not any moving parts at all. Thus, it would be more rugged and less prone to mechanical failures compared to the gimballed systems. However, the computational burden becomes higher since complex transformations and integrations must be continuously made.

4. Sensor equipment of the device

The measuring device designed for selected parameter measurement is equipped with an Inertial Measurement Unit and a GNSS receiver, forming a strapdown system. It registers values at a frequency of 1 Hz and stores data on a microSD card.

All desired properties are realized by the combination of sensors. The measuring device records all data of interest selected for processing.

The hardware that fitted the brief was supplied by the firm XSENS. The MTi-7 from XSENS is a very potent sensor system that comprises an accelerometer, gyroscope, and magnetometer, which is best suited for accurate real-time motion and orientation tracking. This device is suitable for various applications, including robotics, mobile devices, virtual reality, and industrial monitoring. Due to its compact and low-power nature, MTi-7 is very suitable for mobile or battery-operated applications. The MTi-7 has several built-in communication interfaces, such as USB, I2C, UART, and CAN, thus making it easy to integrate with a wide array of platforms and communicate with many devices.

This device can measure speed, acceleration, inclinations, and the magnetic field, which makes it possible to track motion and orientation precisely in real-time—figure 2. The MTi-7 operates at a very wide temperature range; hence, it can be used in demanding applications. It also offers interfaces that are in combination with GPS and other sensors to support combined navigation, making it useful for outdoor position tracking.

Figure 2. Hardware equipment of the measuring device. The authors' own material.

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The device is delivered with a power software package for calibration and processing data, which facilitates development and implementation. XSens MTi-7 Development Kit includes all the development tools and documentation necessary for the fast development of applications working with a sensor. This Development Kit provides access to the API used for programming and configuring sensors and allows developers to set up the device according to their needs.

The MTi-7 development kit is a Global Navigation Satellite System/Inertial Navigation System module, a small, multi-GNSS receiver-supported motion-tracking module. To check on the positioning and accuracy of the map, we decided to compare, at the first stage of verification, the accuracy of map data against the measured data.

Table 1. Samples of measured data

Latitude[deg]	Longitude[deg]	Altitude[m]
48.4284672	20.3335072	191.093
48.4286016	20.3335680	191.186
48.4287360	20.3336272	191.248
48.4288704	20.3336880	191.233
48.4290048	20.3337504	191.236
48.4291456	20.3338128	191.184
48.4292832	20.3338752	191.101
48.4294240	20.3339392	191.052
48.4295648	20.3340032	190.995
48.4297088	20.3340672	190.933
48.4298560	20.3341328	190.864

The verification of measured data takes place in the QGIS program, where individual coordinate points are transferred and overlaid with map backgrounds. In the QGIS environment, plotting the path from GPS coordinates obtained from the GNSS receiver is possible. An elevation profile of the track is drawn using altitude and recorded changes in pressure. The overlay of these layers can be seen in Figure 3.

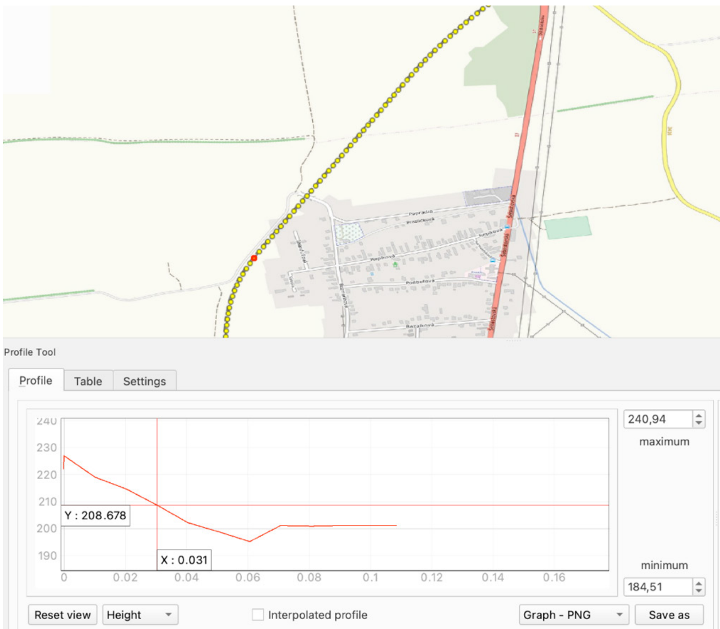

Figure 3. The presentation of GPS coordinates on a processed map background. The authors' own material.

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Above is the picture of the recorded plotted measured data from the device. Every point represents the GPS coordinate system, while the graph at the bottom of the picture shows the elevation profile of the track. The red point on the picture shows the point on the track with an elevation of 208.678 meters above sea level. This measured point is located near the city of Košice, where it differs in altitude from that shown on the internet by five meters.

In the second case, on map picture 2, there is the station Mníšek nad Hnilcom, where on the track profile there is measured height of 419.636 meters above sea level, as marked with a red dot in the Figure 4. The height available on the internet indicates an elevation of 431 meters above sea level. As a result, the difference between the measured height using the device and the height reported on online maps will be 11.364 meters. Similarly, all the surveyed non-electrified tracks are plotted.

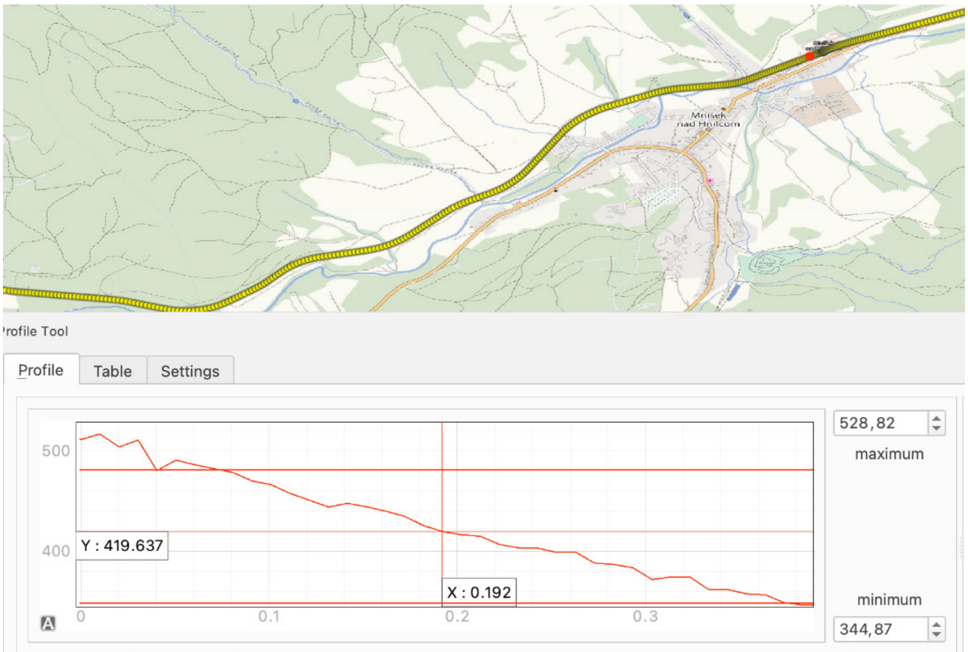

Figure 4. The presentation of GPS coordinates on a processed map background. The authors' own material.

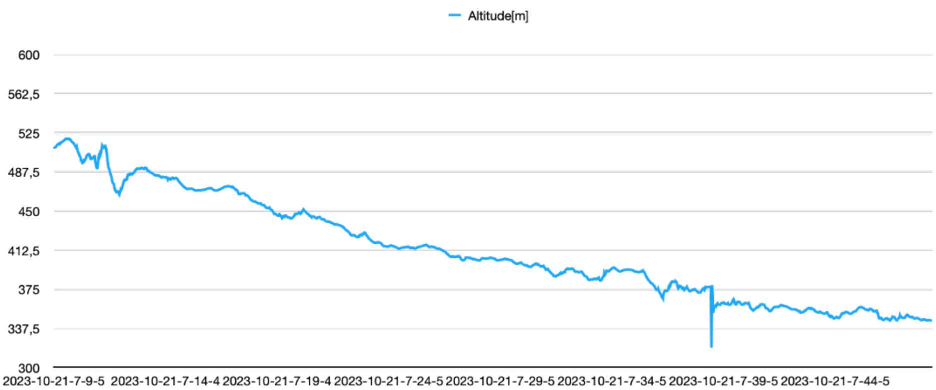

Figure 5. Height profile of the track from Figure 4. The authors' own material.

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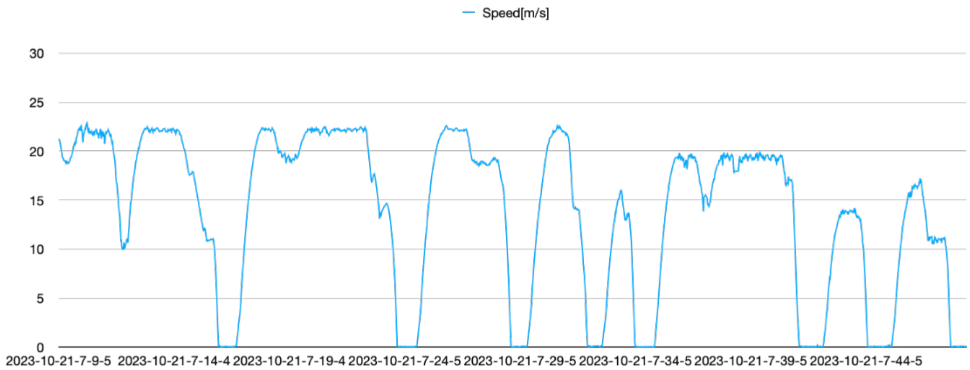

Figure 6. Speed profile of the track from Figure 4. The authors' own material.

Such differences are found along many tracks, and with accurate data, it will be possible to create a model that determines which propulsion system is suitable for each track.

The database containing the measured data will continue to be processed, and advanced mathematical tools will be employed to determine whether there is a partial or overall energy demand for the mapped territory's tracks.

The measurement technique used in track measurements is based on the space and aviation industry. The inertial measuring units are applied to navigation in planes, ships, and other means of transport. This navigation system contains two components: the gyroscope and the accelerometer. An accelerometer measures acceleration besides the gravitational acceleration. The gyroscope measures the angular accelerations. A combination of these two sensors makes it possible to sense the track inclinations, bends, and turns.

Together with GNSS, the inertial navigation system becomes more accurate. The chosen device achieved the required precision, which was necessary for the exact measurement of track conditions. The device itself is fitted with monitoring LED signaling. When the device is powered on, the LED lights up blue. The blue color remains during the initialization of the device. The initialization phase includes the capture of a stable GPS signal and simultaneously the gyroscope alignment.

During the measurement and recording of data, a green light appears. When a red light flashes at a frequency of 4Hz in red, this tells the user that the device is running constant self-checks in the background.

The red indicator pops out in the case of device malfunction. In the absence of a recording medium within the device, it illuminates red.

During operation, the accelerometers continuously measure the specific force along their respective axes, while the gyroscopes measure angular velocity about their axes. All this raw sensor data shall be collected at a high sampling rate.

Gyroscope data on angular velocity is used in computing the orientation, that is, attitude, of the platform in space. It can be done based on a method of quaternion integration or direction cosine matrices. The attitude information can then be used to transform the accelerations from the body frame into a navigation frame, usually global or local inertial.

5. Conclusion

For a successful transition to green transportation, it is crucial for companies to approach the shift to alternative propulsion responsibly. To select a suitable alternative propulsion, it is necessary to have data on track profiles and the achieved speeds in regular real-world operations. This allows determining the actual driving conditions on selected routes where, in the future, vehicles with hydrogen or hybrid propulsion could be deployed due to the green transportation transformation. Of course, the collected data will assist in selecting and locating fueling and service points for chosen propulsions based on calculated consumption on specific track profiles.

After processing the results of the measurements and assessment of availability for every single drive technology, it becomes possible to deploy drives with different types of fuel.

A deep analysis will be required regarding the results of all measurements taken. These will include natural measurements of the physical features of the tracks, but also the environmental and technical parameters that may have an influence on the functioning of the different drives. All data relevant for the consideration of possible challenges and opportunities shall be analyzed in detail.

This shall be followed by the availability assessment of the single drive technologies. It simply means that one has to assess what drive systems are currently available on the market, what are their costs, as well as technical and environmental

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characteristics. In addition, one also considers the logistics and infrastructure required in operation, such as the availability of fuel, the charging stations, and service.

When these steps are completed, a propellant with various kinds of fuel can be commenced. It involves the changeover of alternative fuels, such as electricity, hydrogen, biofuels, or any other environmentally friendly propellant. Each of these drives has its merits and demerits that must be considered when their implementation in real operation is enacted.

This means that the integration of these drives requires preparedness not only technically but also in terms of training personnel and modifying operating procedures. This means that everyone involved in the process must be well prepared for such a transition and must be provided for a smooth and efficient integration of new technologies into the system. Only in this way can numerous problems be fixed, like the reduction of the negative environmental impact caused by transit.

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Declaration of interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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