TRANSPORTING FROM THE SOUTH AMERICA´S LITHIUM TRIANGLE: SUSTAINABLE CHALLENGES IN MEETING THE WHITE GOLD RUSH

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Abstract

Sixty percent of global lithium identified reserves, a key element in the transition to renewable energy, are located in La Puna (Argentina, Bolivia, Chile). An arid, mostly uninhabited and inhospitable plateau with elevations of around 4,500m above sea level, La Puna will experience a rapid increase in road transport needs in the coming years with a significant social and environmental impact. Our paper suggests that increasing stakeholders' pressure associated with multinational mining companies´ sustainability disclosures, is the right trigger to motivate willing local transport companies in the use, adaption and training of proven safe and productive transport technologies, as the experiences shared by two local companies illustrate.

The paper describes a Distributed Aiding System for Driver Decision Support, a modular, standalone, non-invasive system specifically developed to deal with the challenges present in GPS denied regions. The system uses diverse sensing, processing and communication capabilities to share 24/7 relevant information, resulting in safe in-advance awareness that allows drivers to take actions and even plan in advance, well before risks are visible. Developed and successfully implemented by one of the authors in private mining companies in Australia, its adaption has seen expressions of interest to pilot the system on public roads.

Keywords: Lithium, Mining, Sustainability, Supply Chain, Driver Decision Support systems

1. Introduction

Lithium has become a key element in the transition of the global economy from fossil fuel to renewable energy. Lithium production has increased worldwide by over 20 percent in 2022 (U.S. Geological Survey, 2023) and, as the world produces more batteries and electric vehicles, the projected demand for lithium carbonate equivalent (LCE) suggests production needs to triple by 2025 and increase nearly six-fold by 2030, from 2021 production (World Economic Forum, 2023). South America´s “lithium triangle” is an area that holds an estimated 45 percent of global proven lithium reserves in the world, excluding the USA (U.S. Geological Survey, 2023) and 60% of identified reserves. Also known as La Puna, it is an arid, mostly uninhabited plateau with elevations of around 4,500m above sea level characterized by its dry, cold and changing climate. Three countries, Argentina, Bolivia and Chile, share borders in La Puna, thus country and provincial road heavy vehicles´ regulations, standards and specifications differ.

Global companies from Canada, China, France and Australia are investing in large-scale projects in La Puna. Only in Argentina, there are currently thirty-six advanced lithium projects in diverse stages of development (see Figure 1), which could have a potential production of 291,000 ton/year of LCE (Ministerio de Economía Argentina, 2023). Note the map is from 2019, when many of these projects were still not operational.

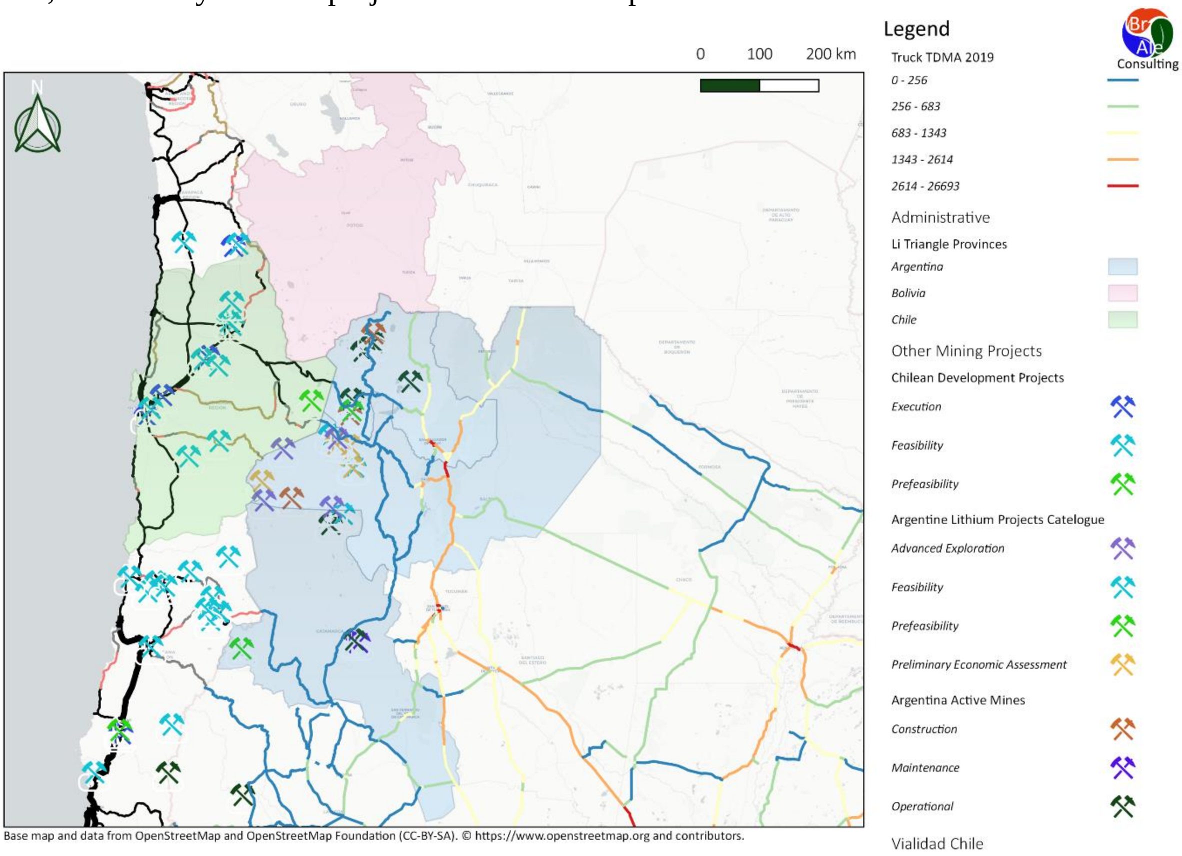

Figure 1: Map of La Puna showing new projects and road infrastructure, Source:authors, data Economy Ministry 2023, National Roads 2021

With mines other than lithium such as copper, gold and silver in the area, the increase in road transport needs in the next years (both uphill with supplies for the mines and downhill with product) will have a very high social and environmental impact.

Among the driving challenges of La Puna, some are:

- thermal daily variation of 30 to 35 degrees Celsius (e.g. 13C to -20C in a single day);
- severe erosive processes due to blistering winds, frequent and intense frosts, ice on the road and solidified narrow creeks which can alter road position and conditions on a near daily basis;
- steep slopes, hairpin curves and precipices;
- free roaming animals and tourists in light vehicles and motorbikes;
- driving towards the sun for a very long periods of time;
- limited or nonexistent communication signals for long stretches of the road.

Mandatory reporting of sustainability impacts and risks is becoming more prevalent. Legislation such as the European Unions' Corporate Sustainability Reporting Directive (CSRD) (European Commission, 2023) and the United States' Securities and Exchange Commission (US Securities and Exchange Commission, 2022) are examples of regulators demanding supply chain level disclosures of environmental and social data.

Given the nature of their activities, multinational mining companies have been reporting to voluntary frameworks such as the Global Reporting Initiative (www.globalreporting.org/) standards, the United Nations Sustainable Development Goals (SDGs) (United Nations 2015), and CDP for many years. These frameworks not only refer to the pressing need to reduce greenhouse gas emissions from freight transport, but also address social impacts including road safety, enhancement of quality of life, job and education opportunities, age, and gender inclusion.

In addition, concepts such as Australia's National Havey Vehicle legislation's Chain of Responsibility (NHVR, 2014) require mining companies to encourage and enforce the using of best available road transport safety technology.

The heavy vehicle transport systems and technologies can contribute to some of the sustainable challenges the mining supply chain has in meeting the white gold rush in the harsh La Puna environment. Our paper argues that the multinational companies´ sustainable reporting requirements on their global supply chains may be just the right trigger to motivate local transport companies in the use of safe and productive heavy vehicle transport technologies and systems.

The paper is divided into three parts. Firstly, the authors introduce the reader to the challenges that La Puna presents to road heavy vehicle transportation. A second part refers to the social license to operate, where two local road freight providers share their experiences in building local capacity at over 4000-meter altitude to cope with future heavy transport needs. The third and last part shows a project in development by the authors, a Distributed Aiding System for Driver Decision Support, to mitigate accidents where there is limited, sometimes non-existent communication infrastructure.

2. Some Challenges for Road Heavy Transport Technologies in La Puna

With mining booming in the area, road transport to and from the mine sites present health and technical difficulties. On the Argentine side, paved roads are practically nonexistent, mostly gravel or packed sand which sometimes move around as the wind blows the surface away (see

Figure 2). From Argentina or Chile, the abrupt descent from very high altitude from over 4.500 meters high to less than 1000m, with very severe gradients, is challenging on vehicles and human resources alike, both uphill and downhill.

Figure 2: Observations in everyday operating conditions. Source: Authors, 2023

Extremely harsh weather conditions, winds of 80km/h with gusts of up to 130km/h make traveling time sometimes unpredictable and driving dangerous, for loaded and empty vehicles. Fully loaded configurations downhill in paved roads make hydraulic retarders in the transmission and engine brakes essential. A common accident is brake fading downhill, where there are no escape ramps. Maintenance cost for brakes and tyres are significant.

The change in ambient temperature can be extreme, especially at nighttime. Sunlight, though extremely strong, just bounces off the white surfaces, and does not heat the ground. As a result, temperatures drop instantly once the sun goes down, and can vary in summertime, from +10C to +30C in the lowlands, to -17C to +10C in the Puna (in winter temperatures can reach -30C). The only diesel fuel available, however, is summer fuel, with a freezing point of maybe +3 °C, so fuel freezing is an always present dangerous risk. Well insulated cabs, which are common in cold countries, are not produced or sold in South American vehicles.

The low ambient air pressure and frozen batteries make starting the engines a difficult task. Heating batteries and fuel tank with an alcohol burner and placing a flame in the intake manifold are normal practices. The low ambient air pressure is also known to cause problems of cavitation in hydraulic pumps with steering systems whining and cooling water boiling away at 85 °C.

Healthwise, "*environments significantly above sea level expose travelers many problems, with hypoxia being the biggest concern*", according to the USA´s Center for Disease Control and Prevention (CDC). The "*apunamiento*" or acute mountain sickness (AMS) is in the High Category (over 3,500 m of ascent in 1 day), and simple tasks such as changing a tyre becomes a massive challenge. Drivers therefore need not only have experience in working in La Puna, but also be fit not to succumb to the drowsiness and fatigue the place provokes.

This "Puna effect" also affect the vehicles. Trucks operating in La Puna suffer the effect of loss of power at altitude7, if with turbo approximately 25% power loss, and without turbo around 40%.

Multinationals involved in mining have to produce annual sustainability reports showing reduction strategies for accident and potential incidents. The use of compulsory heavy vehicle technologies and systems requested from their transport providers has increased. Many of these requirements are non-expensive retrofit devices which are manufactured and/or installed and maintained locally, such as the integrated tyre inflation systems, or the cooling and heating systems for when the engine is off. Others safety requirements may involve higher investment or purchasing of newer powerful vehicles (6x4 and over 540HP) with all of the safety features OEMs offer, but are available as optional safety package.

For example, in Argentina, all tractors produced since 2014 on, must have ABS brakes, but when looking at semitrailers, very few of them have ABS. Trailers without ABS, even if towed by new tractors, are prone to jack knifing accidents, especially when empty and on slippery roads, rain, dust, gravel, and very much so on curves with steep downhill Note the legislation to include EBS and ESP in the new tractors, as well as ABS in the semitrailers was many times postponed, the latest postponement until 2025.

Suspended dust, calamine, boulders, pointed stones and the sinuosity of the route directly influence the maintenance costs of the equipment, causing punctures or bursting tyres, which means a loss of time in traffic and a risk also for the driver who must make the change in these extreme and unsafe conditions. Tyre management is key for safe operation in La Puna, since tyres deteriorates approximately 60% of its common operational life. Operators such as the authors have a documented tyre history, from the purchase to the use and to final disposal. While premium brands are usually the ones of choice, purchasing obstacles (strikes, imports) in Argentina have compelled companies to mix tyre brands including lesser quality ones to be able to continue operating. Final disposal is usually done in a sustainable manner, either through government or private programs.

Most companies use conventional 5 axle configurations of 45 gross vehicle mass (in Argentina and Chile), or the scalable 6 axle configurations which allows up to 55 GVM, in Argentina only. High Capacity Vehicles (VADs in Spanish) have compulsory safety devices and the authors suggest their authorization to travel in La Puna should be studied.

3. Social License to operate (SLO)

Social License to Operate (SLO) may be defined as "*the ongoing acceptance of a company or industry's standard business practices and operating procedures by its employees, stakeholders, and the general public.*" (Kenton, 2023). Unanticipated and unintentional impacts on the rights of local people can pose risks to a company's productivity, reputation and social license to operate in a region.

The rapid expansion of mining in the La Puna is anticipated to put pressure on the region's populations' willingness to accept dramatic increases in vehicle movements and associated impacts on air quality, road safety, quality of life and competing industry sectors such as tourism. Failure to ensure local communities' ongoing SLO leads to legal actions and local mobilizations impacting mining operations. (Gonzalez and Snyder, 2020)

BrAle has been hired by multinational developers in La Puna region to engage in continuous improvement of local transport operators. Aspects include investigating best available technologies as well as adopting chain of responsibility systems. Participating transport operators welcomed the opportunity to improve their systems as a way to develop scarce local talent and encouraging women in logistics services, including truck driving.

Two of the paper authors, GVH Minería Transporte de Altura and TFP, are two local transport companies working in La Puna. GVH is a family company with over 20 years of experience in road transport in la Puna Argentina. One of the brothers was founder and vice-president of Chamber of Mining and Tourism Service Providers of the Puna (CAPROSEMITP), the first SME chamber in the country of indigenous peoples. TFP is a local logistics family company which works on both sides of the Andes mountains. Both companies have grown with the mining industry and have been part of the balancing act between achieving social commitment to the local communities, local governments and the international companies. "*Native entrepreneurs have managed to change their lives. Current mining companies are leaving an incredible development in the area*", said the general manager of GVH.

In their exchange and to ensure their own business for the longer term, both companies have developed the driving skills of their drivers, as well as developing training programs with the native communities in support activities, which contribute to a fast and effective solutions when there is an incident. Part of this training is on road safety procedures, with KPIs for continuous improvement. OEMs offer driver training, and, as requested by the mining companies, drivers also undergo training and inductions within the company on drowsiness procedures, defensive driving, use of safety elements, how to act in the event of an accident or incident, to name a few. The CAPROSEMITP offers driver courses too, which even include English language modules, very useful for the locals to communicate with global companies. Courses provided by the new School of High Mountain Drivers and the Chamber include appropriate driver behaviour to comply with international safety standards.

Technological elements on their own do not always improve productivity and road safety. Training on the correct use of the technologies and devices included in the vehicles is crucial, since their correct use returns economically both to the private sector, the society and the State, while incorrect use translates into greater fuel consumption, increased tyre wear and damage to road infrastructure, coupled with an increase in road insecurity (Efrón & Corvalán, 2018).

4. Improving Comms – A Distributed Aiding System for Driver Decision Support

Rain, snowfall and strong winds cause road closures that can delay traffic for more than a day, in addition to driver safety issues. The landscape changes are so sudden and communication infrastructure is so limited or non-existent, that most multinationals request support vehicles to escort the heavy vehicles, besides a satellite phone with the driver.

The Distributed Aiding System for Driver Decision Support is oriented to provide safe perception under diverse harsh environmental conditions such as the ones described in La Puna. The system perceives, infers, and reports difficult road & context characteristics, increasing driver awareness and enabling the driver to make informed based decisions to avoid potential accidents or incidents.

The system exploits concepts and resources for reliable and feasible generation and sharing of information, which allows to distribute perception and inference of risks, thus implementing the capability to dramatically improve awareness in vehicle drivers (being those drivers human or autonomous), usually providing valuable information, well in advance, and thus mitigating risks of accidents and also reducing numbers of abrupt actions which may be, in addition to risky, inefficient in terms of productivity and inadequate in terms of the treatment of equipment (e.g. aggressive manoeuvrers).

Figure 3: Part of the road to the mines, Source: authors, August 2023

The Distributed Aiding System has been previously tested and accepted in harsh mining contexts, for other industrial purposes, on private roads. A number of mining operators and logistics service providers in the La Puna region have expressed interest to pilot the system on public roads.

4.1. Virtual Network

The virtual network (VN) is a concept initially introduced in 2005, (Nebot and Guivant 2007), for providing adequate sharing of information under limited communication resources. The information is shared between trucks and other vehicles in large open mines, in which communication infrastructure is not available or where the coverage is deficient in temporal and geographical terms.

The approach is fully scalable, not requiring pre-configuration, and is dynamically adapted to the circumstances (distribution of vehicles, optional static infrastructure, and auxiliary agents such as perception dedicated agents).

Advantages of the VN technology are that it reduces long range communication traffic and allows the usage of reliable low bandwidth Radio Frequency (RF) channels in a parsimonious and robust manner. In addition, it achieves high reliability and diverse levels of redundancy, and immunity to hostile actions.

The system is able to utilise diverse communication technologies, simultaneously, being those local (short range RF radios) and also long-range communication, based on cellular or satellite comm services, always balancing reliability and operational costs.

4.2. Perception for active learning of road conditions

The system is designed to learn the context, based on distributed perception, installed in some of the vehicles. The perception process is dynamically scalable and robust with respect to failures of the nodes/vehicles, which are unusual but possible.

Based on advanced processing and on distributed perception capabilities, the system would also operate at night providing valuable information to increase awareness of drivers.

Conveniently, the system will help to deal with non-participant vehicles, i.e., those vehicles that are not connected with the system, e.g., tourists' cars and public in general (this capability is possible in cases in which some of the participant vehicles are equipped with perception capabilities (the so called "active agents"), such as camera and/or LiDAR and RADAR sensors.

Particularly valuable aiding is provided to "follower trucks", in convoy operations, in which follower trucks are affected by the dense dust generated by leading vehicles ahead, decreasing visibility, which usually affects human drivers and, as well, sensors capabilities typical in autonomous driving systems. If the leader truck is one of the perception-enabled units, it will be able to share information describing the context of operation and even about the presence of non-participant vehicles which may represent a risk to perception impaired participant trucks.

Detailed real-time analysis of road shape and conditions (potholes, debris, ditches, etc) is provided, being the risk estimation processes some of its benefits. This real-time scanning resource is considered industrial grade, as it will operate in difficult weather conditions, 24/7, based on industrial grade LiDAR and RADAR technologies, properly processed thorough advanced state of the art approaches. The mentioned scanning hardware has been successfully/reliably used in harsh mining contexts by the developer of this proposed system. (E Nebot, J Guivant (2006), E Nebot, J Guivant, S Worrall (2006), JE Guivant (2014)

4.3. State of the art processing for perception

Some of the vehicles have on-board perception (based on the data provided by the sensors). The perception modules are in charge of inferring the road and the features. Some relevant features are called OOIs (Objects of interest). Those detected OOIs are classified and modelled, for estimating risks.

Typical OOI are road potholes, ditches, humps, depressions, narrow road sections, etc. Other context related OOIs (e.g., pedestrians, animals, non-participant vehicles) are also inferred by the system; drivers are made aware of any OOI which may imply a risk, within adequate time in advance.

The system uses the knowledge about the presence and type of risk to inform the driver. That knowledge about the OOIs is the result of the on-board perception processes, or the result of shared information generated by other vehicles. This last source is particularly relevant for vehicles that do not have on-boards perception capabilities.

For instance, a leader truck in a convoy formation, if equipped with sensing and processing resources, can detect OOIs near the road, and so automatically inform the follower vehicles about that fact. The presence of certain types of OOIs is also shared with other vehicles, via the virtual network, i.e., not only with those vehicles in the convoy formation mentioned above. The presence of OOIs is usually known by all the participant vehicles, via the efficient data-sharing process.

4.3.1. Active friendly assistance of drivers.

The system is intended to help context awareness of truck drivers. The way for the system to communicate with human drivers can be configured to include different modalities, simultaneously, as particular vehicle operators may require different modalities at the moment the risk are inferred from the knowledge about OOIs (Voice, Visual and/or alarms (beeps)).

4.3.2. Additional aiding

Active agents (trucks equipped with scanning sensors) could be beneficiaries of extra features, such lane departure detection, even in roads in which no lane signs are available (such as those on asphalted roads in which lane lines are painted).

Real-time perception and processing allow the inference of road boundaries, based real-time 3D road modelling and on accurate relative pose estimation (note: NO GPS is required). The system estimates the pose of the truck respect to the road being travelled, which is modelled in real-time by the truck itself. In this way the drivers can be made aware if they are driving on improper positions (e.g., too close to road boundaries). This capability is independent of the other functionalities of the system, and, for that reason, is not affected by the presence or absence of those.

The system is designed to satisfy convenient characteristics such as:

- **Easy deployment.** Although the system is complex in terms of capabilities, that does not mean that it is complex in being deployed. It is designed to be modular for easy installation and maintenance.
- **Self diagnoses.** The system always verifies the proper operation of its components. No FALSE negatives would occur due to sensor failure.
- **Easy cost-effective maintenance.** It is cost effective due to the way by which the usually expensive advanced sensing resources (e.g., scanning sensors) are deployed and efficiently used.
- **Non-invasive.** There is no need to invade/touch / connect many components to other vehicles systems, so that we do not generate disturbances to those systems.)
- **Configurable.** Capabilities and components of hardware and software are configurable. From the perspective of the users, a rich set of features, in the software, are configurable in a friendly fashion.

4.3.3. Operation

Figure 4 illustrates the LiDAR installed in mining truck (with protection from rocks). This model of sensors has been well tested and accepted in harsh mining contexts, for other industrial purposes. the proposed system is intended to provide a good balance of cost, reliability and performance, in contexts of operation which are highly difficult and in which no other alternatives are industrially available (due to the complexity of the problem and also due to the economic feasibility as this type of context does not result in a massive market.)

Figure 4: Industrial LiDAR, installed in a truck, laterally" (Truck Guidance System, 2005) (as used in E Nebot, J Guivant (2006) and [E Nebot, J Guivant, S Worrall (2006)

Figure 5 below shows a section of the road, being modelled, in real-time, by one of the perception modules. LiDAR scans are fused for generating a 3D description of the section, from which certain OOIs are inferred. In the image, lateral depressions are detected (shown in red, for simple visualization of that type of inferred OOIs), and considered to be imply certain risk, and clearly used to infer the boundaries of the safe road.

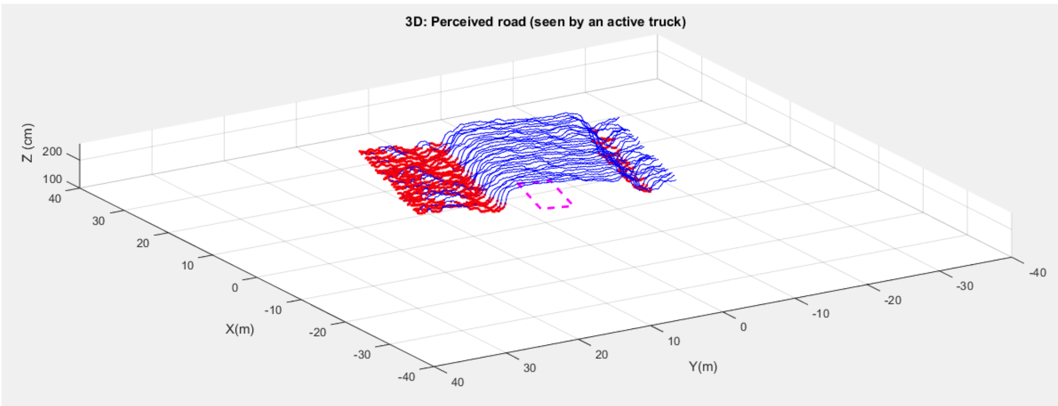

Figure 5: Example of LiDAR perception of road surface and drainage, Source Authors

Figure 6 shows a visualization of an instance of data sharing, by which trucks learn about the existence of OOIs inferred by other trucks. This makes drivers aware of risks well before those risks are reached by the vehicles they drive. Figure 6 also shows the newly defined dynamic GeoFence (yellow rectangle), proposed by the system as result of the detection of relevant risks in that sector of the road.

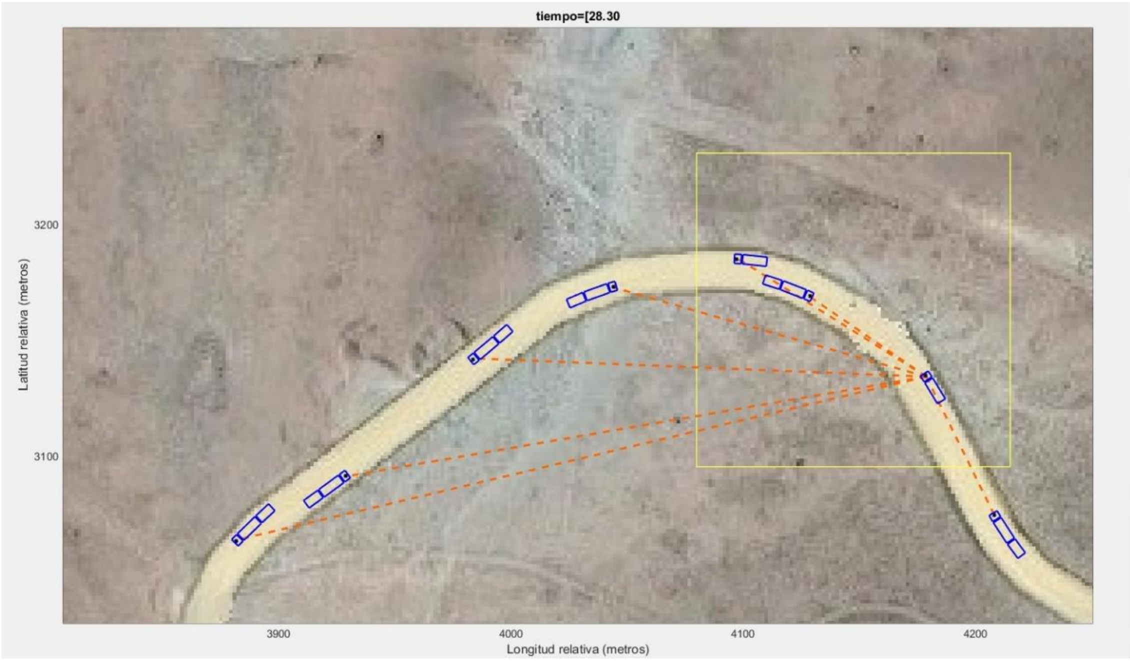

Figure 6: Visualization of an instance of data sharing in simulation, Source authors 2023

The system is configurable to allow operators to set how early (in time and/or distance terms) the drivers should be informed about the existence of risks, when those are updated by the distributed learning and inference process.

The aiding system does the sensing and processing, infers, reports, and the driver is made aware of the risk with enough time to make a decision on how to deal with that risk. For example, if the driver in Figure 7 had been made aware of this lateral ditch, probably would not have been in this situation.

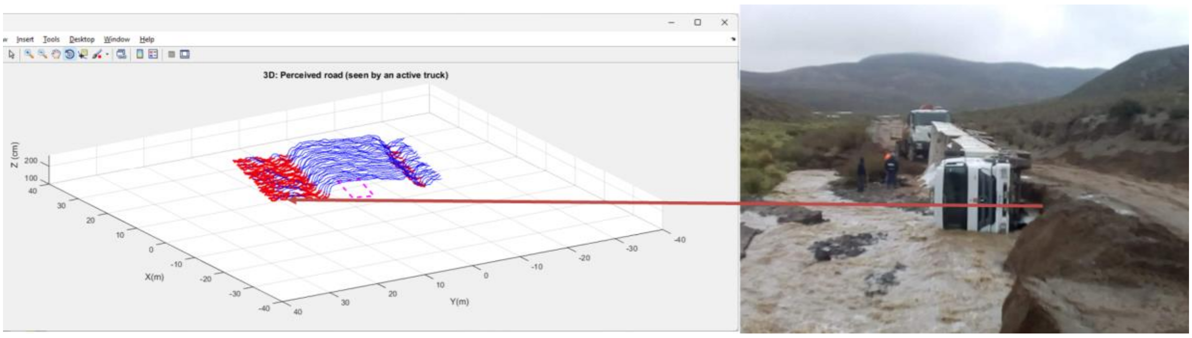

Figure 7: Example of how it works for a typical OOI (lateral ditch invading road) Source: Authors 2023

5. Conclusions for further discussion

Implementation and adaption of heavy vehicle transport technologies and systems in regions such as La Puna present challenges from a social, economic, environmental and governance perspective. Compulsory sustainable reporting by multinationals, including the license to operate, has become a new change driver to try these adaptions with those local heavy transport companies who foresee value in saving and enhancing the lives of the local communities. These are the type of partner companies which are keen in improving their operations to higher standards international companies require.

Proven and accepted safety and driver aiding systems, such as the ones described in the paper, could be adapted to be used by local operators, if they are appropriately motivated. One example is the Distributed Aiding System, that has been previously tested on private roads. A number of mining operators and logistics service providers in the La Puna region have expressed interest to pilot the system on public roads.

The authors would also like to prompt a discussion on drivers' fatigue management in La Puna, learning and adapting current international practices to have an evidenced based discussion at a government and union level of the benefits of, for example, installing in-cab fatigue management devices with sensors aimed at the driver's face to register eye and head movements. Although proven safe, there have been some complaints from the unions about driver´s privacy rights.

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