An Approach to the Integrated Management of Machinery in the Construction Industry

32nd RTCM Seminar

.CISUC
Centre for Informatics and Systems of the University of Coimbra

CONDURIL

Óscar Sanchez
Duarte Raposo,
André Rodrigues,
Jorge Sá Silva and
Fernando Boavida

Contents

Figure 1: Conduril heavy machinery in the new extension project of Sines seaport

Fourth Industrial Revolution

- A new phase in the industry that focuses in:
  - Interconnectivity
  - Automation
  - Machine Learning
  - Real-Time data

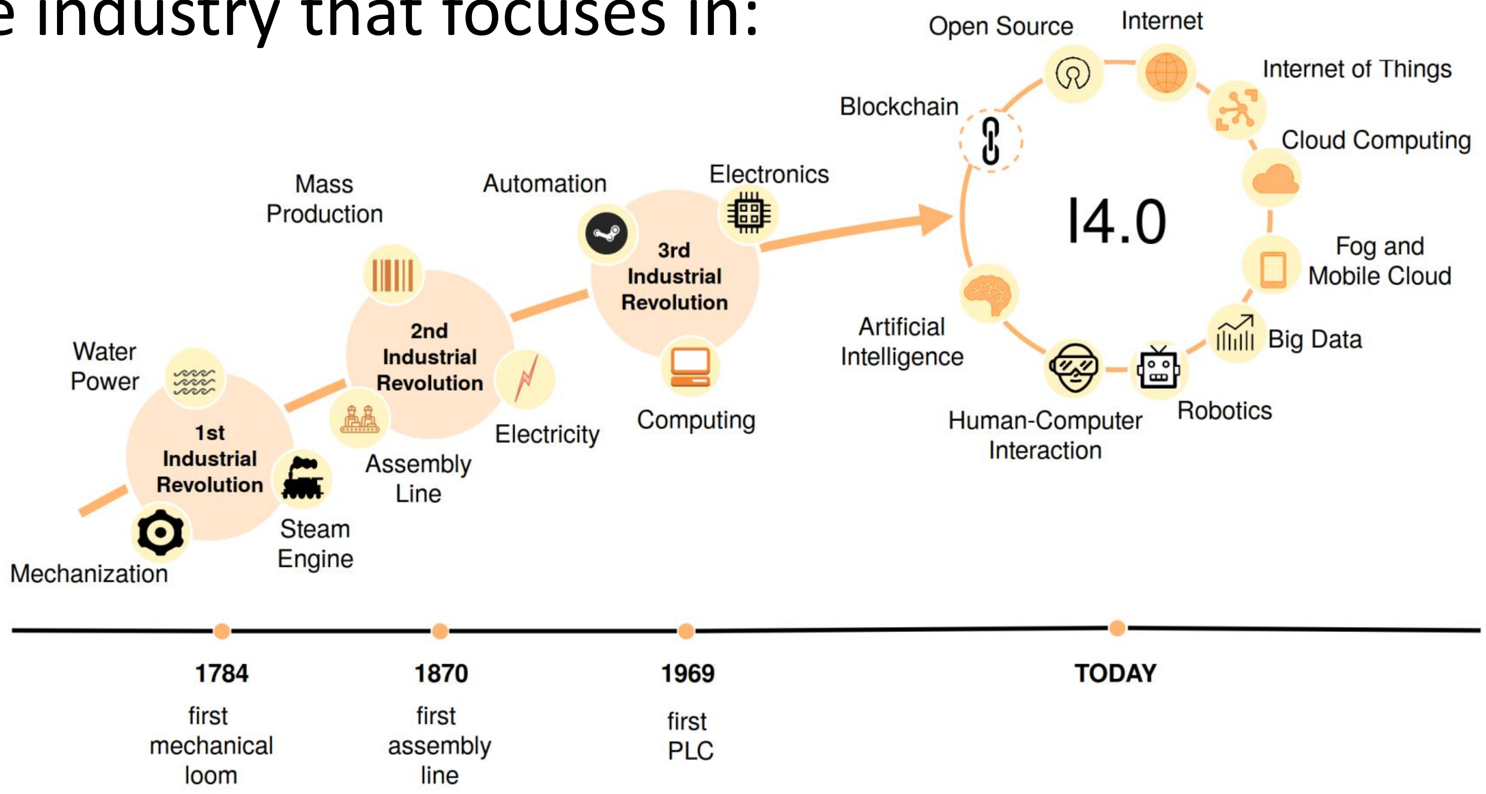


Figure 2: Main enablers for the different industrial revolutions*

* Aceto, G., Persico, V., & Pescapé, A. (2019). A Survey on Information and Communication Technologies for Industry 4.0: State-of-the-Art, Taxonomies, Perspectives, and Challenges. *IEEE Communications Surveys and Tutorials*, *21*(4), 3467–3501. https://doi.org/10.1109/COMST.2019.2938259

Why Construction Industry?

- Construction industry equipment is by large made of heavy machinery that presents a **high maintenance cost**
- On-site heavy machinery breakdowns represent additional costs and delays in the works **(construction delay)**
- Some construction tasks such as earthwork, heavy material displacement, and stabilizing large objects could endanger the machine operator **(operator security)**
- Machine operation good practices reduce operational costs and increases overall operation efficiency

Why Construction Industry?

- The collection of **big in-vehicle data** could be used to build **predictive ML models** capable to detect machinery breakdowns and emergency scenarios on construction site

- The monitoring in real-time of on-site processes could also help to improve the **performance of site operations**

Do you remember why Russians got caught stealing agriculture machinery from Ukraine?

Research Challenges

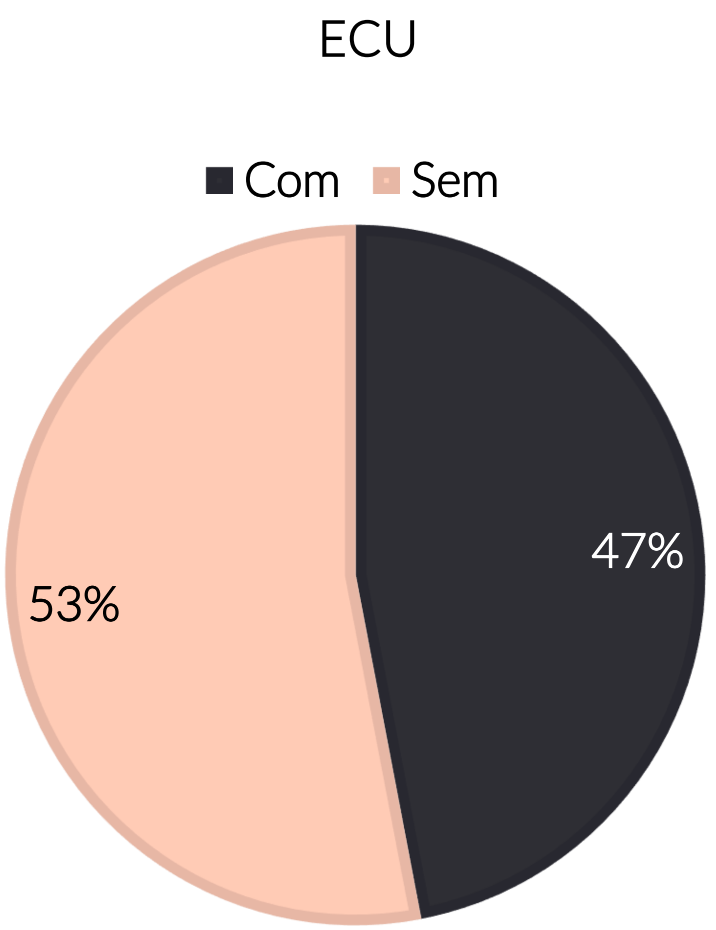
- Off-road heavy vehicles operate in **vast areas without coverage of cellular infrastructure**, representing a different approach from typical V2X networks
  - Need for communication technologies such as LPWAN, with **low operation costs and long range**, not dependent on third-party communication infrastructures

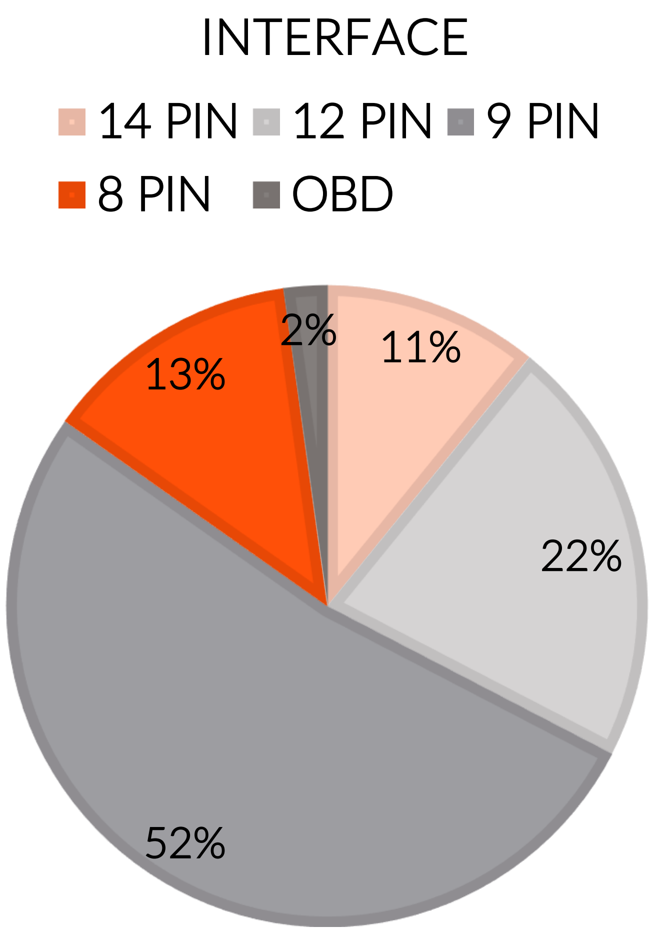
- Integration with legacy systems **is challenging**!
  - In-vehicle data of heavy machinery uses **proprietary messages** encapsulated in well-known protocols (CAN). In off-road vehicles is not mandatory to use protocols such as OBD2 or J1939

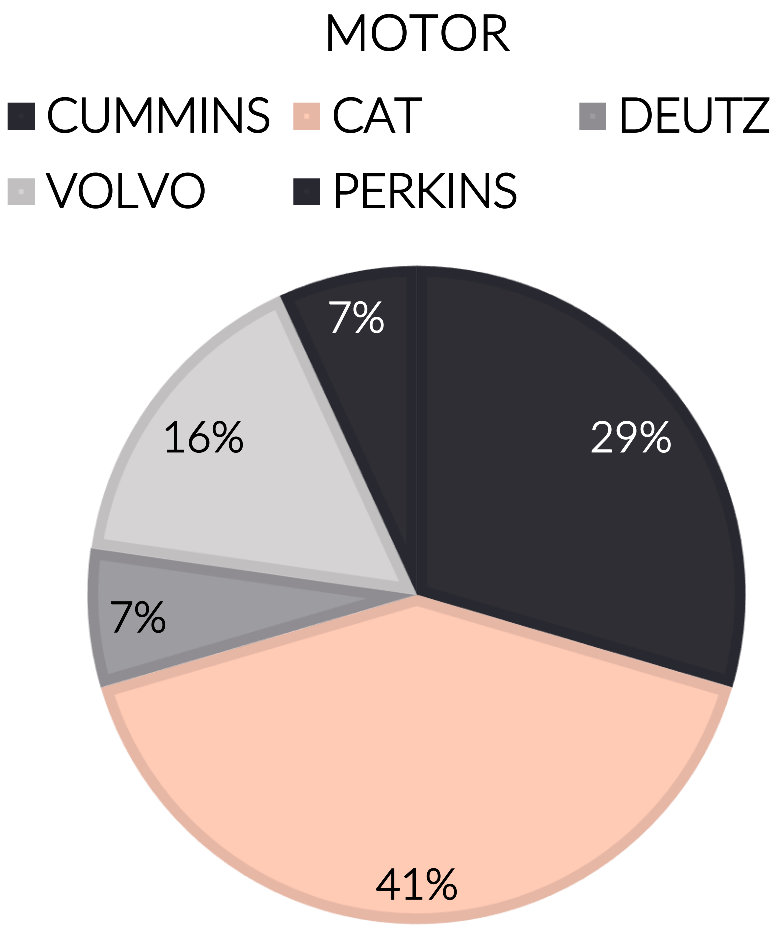
Research Challenges

- The low data rate available in LP-WAN will l**ead to in-node ML (edge) or even federated learning**
- LP-WAN needs to incorporate **mobility models**, and network topologies capable of dynamic self-configuration, self-organization, and self-healing
- Connecting the devices over the Internet could represent **security risks**:
    - The ECU Bus will be exposed to control operations that could represent a security risk to the operator and machine (**hardware, software and network security**)
- Construction industry has **high-reliability requirements**:
    - Connection loss, packet dropping, and weak network response can affect the overall system

Industrial Park - Heavy Machine Analysis



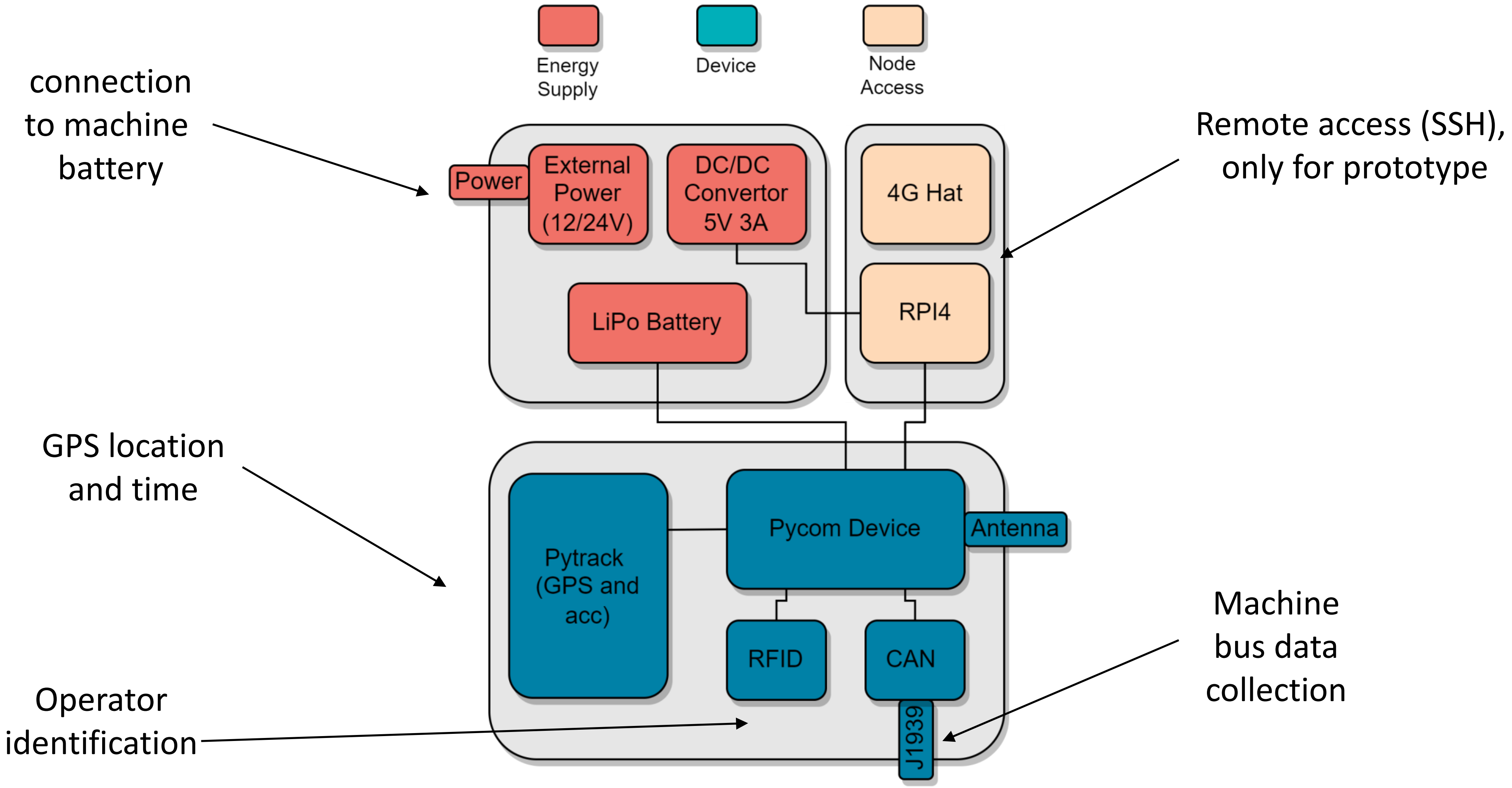




Solution Proposal

- Build a monitoring solution to be installed in the heavy machines capable to collect data from in-vehicle sensors with/without ECU (should support analog sensors)
  - Support CAN bus communication, J1939, and the CDL protocol from Caterpillar
  - Data: machine work hours, movement parameters, an operator identification, fuel consumption and level, water temperature, GPS location,…
- The node should support several technologies based on LP-WAN for communication such as LoRa, LoRaWAN, NB-IoT, LTE-M
  - Additional support for PANs communication (node configuration) such as BLE

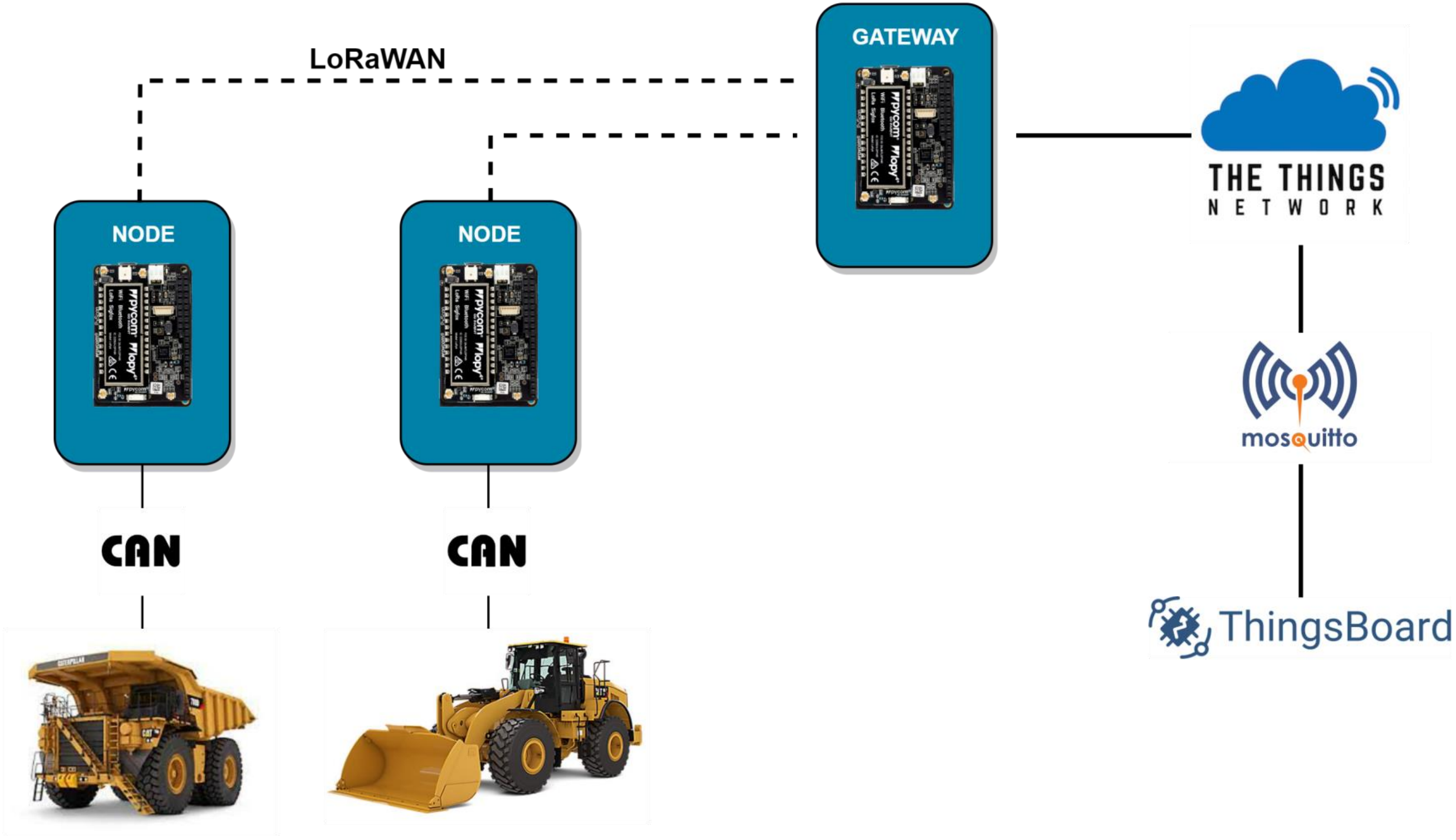
Solution Block Diagram



J1939 Signals supported

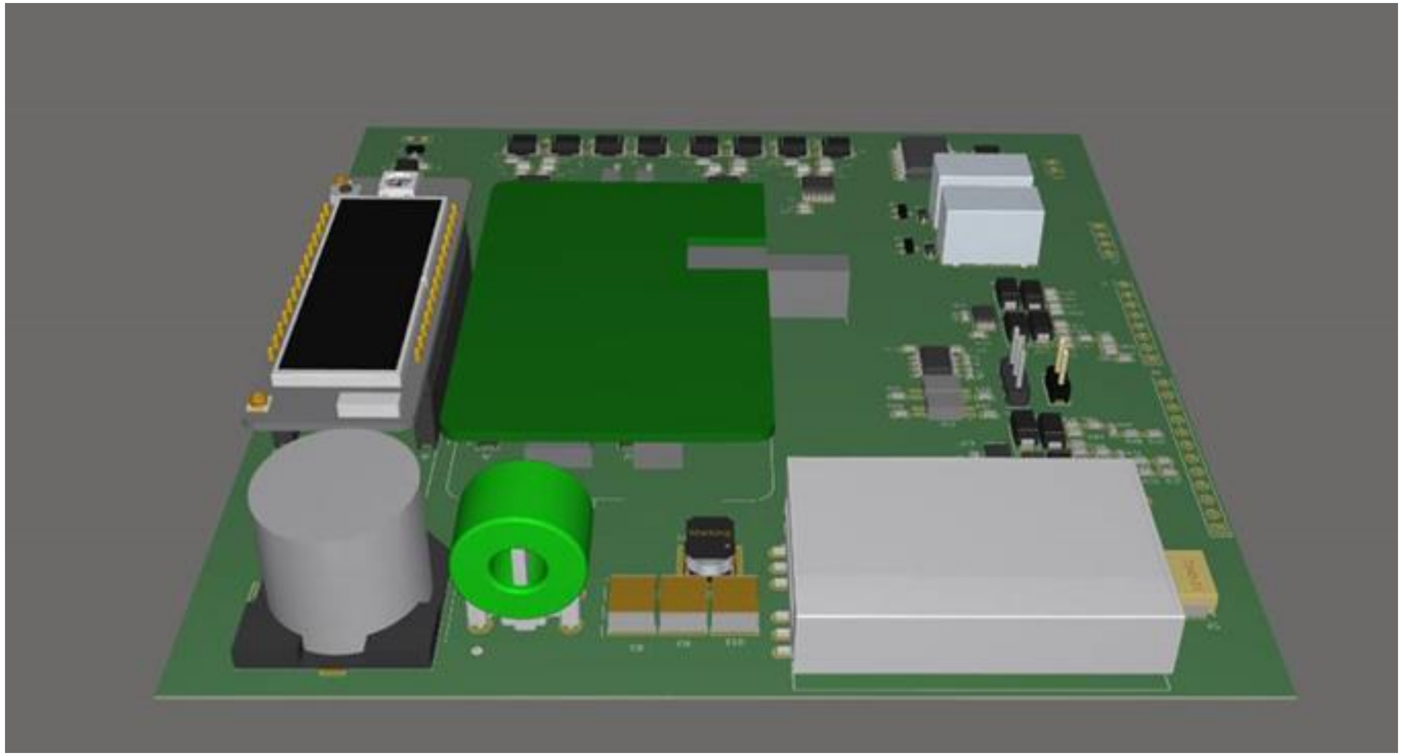
PGN	SPN	Name	Bytes	Position	Unit	Range	Resolution	Frequency
65276	96	Fuel Level	1	2	%	0 to 100	0.4% / bit	1 sec
65262	175	Oil Temperature	2	3-4	deg C	-273 to 1735	0.03125 deg C/bit	1 sec
65188	1136	Engine ECU Temperature	2	3-4	deg C	-273 to 1735	0.03125 deg C/bit	1 sec
65262	110	Engine Coolant Temperature	1	1	deg C	-40 to 210	1 deg C/bit	1 sec
65268	241	Tire Pressure	1	2	bar	0 to 10	0.1 bar / bit	10 sec
65263	100	Engine Oil Pressure	1	4	bar	0 to 10	0.1 bar / bit	0.5 sec
64929	3484	Aftertreatment 1 Fuel Control 1	0.25	7.3	state	0 to 1	N/A	0.5 sec
65271	168	Battery Potential / Power Input 1	2	5-6	V	0 to 3212.75	0.05 V / bit	1 sec
65271	114	Net Battery Current	1	1	A	-125 to 125	1 A / bit	1 sec

Solution Architecture

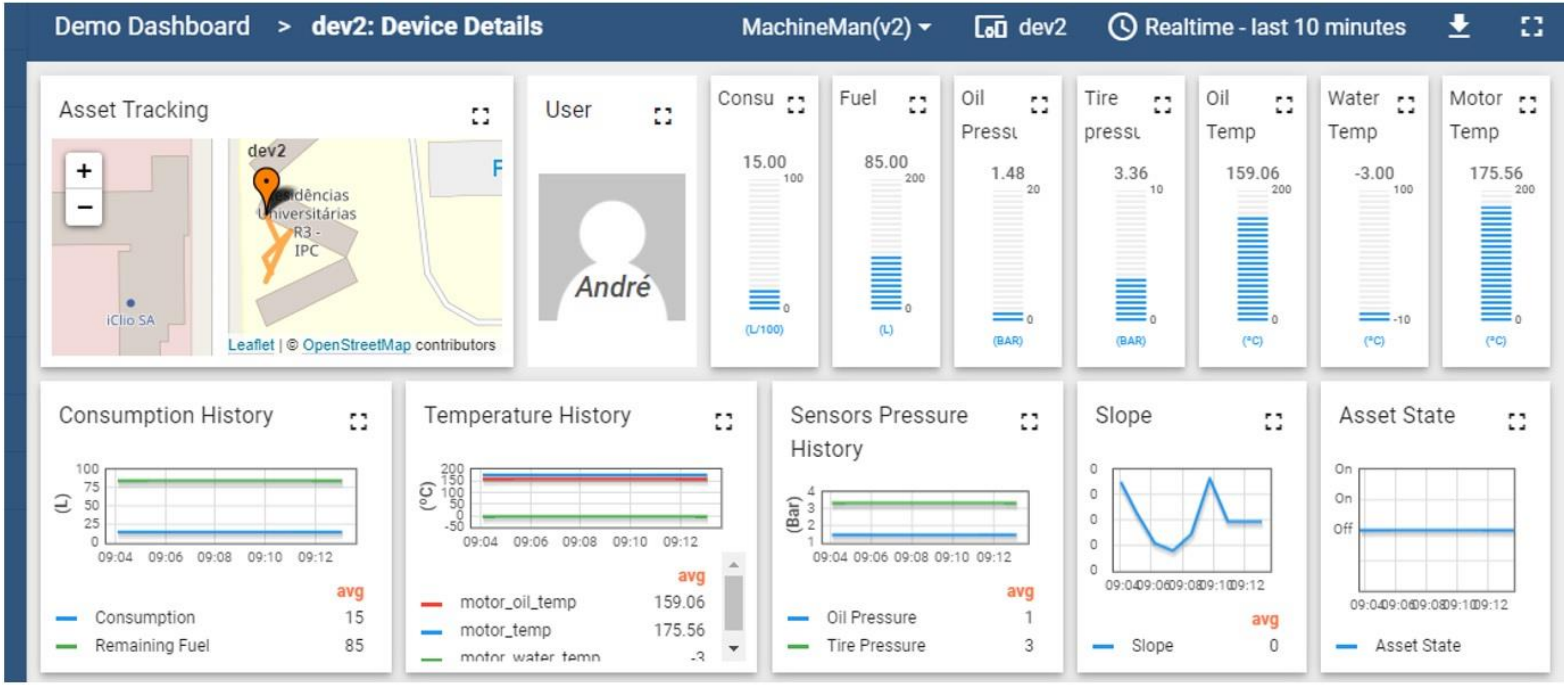


Prototype V1

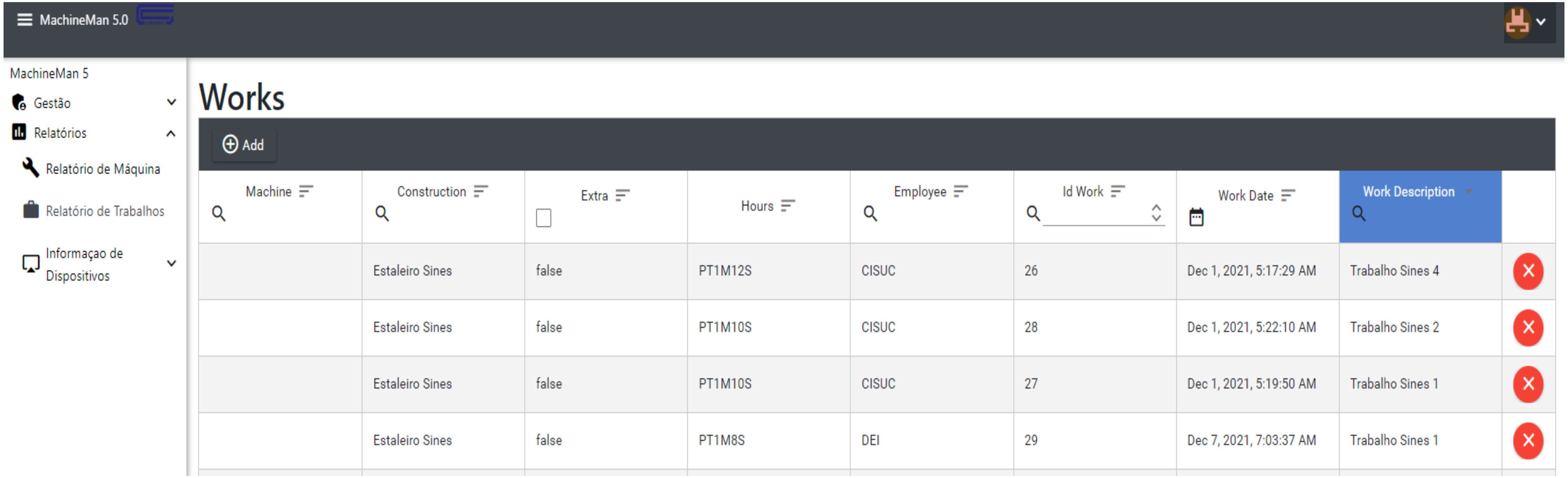
Prototype V2



Management Platform

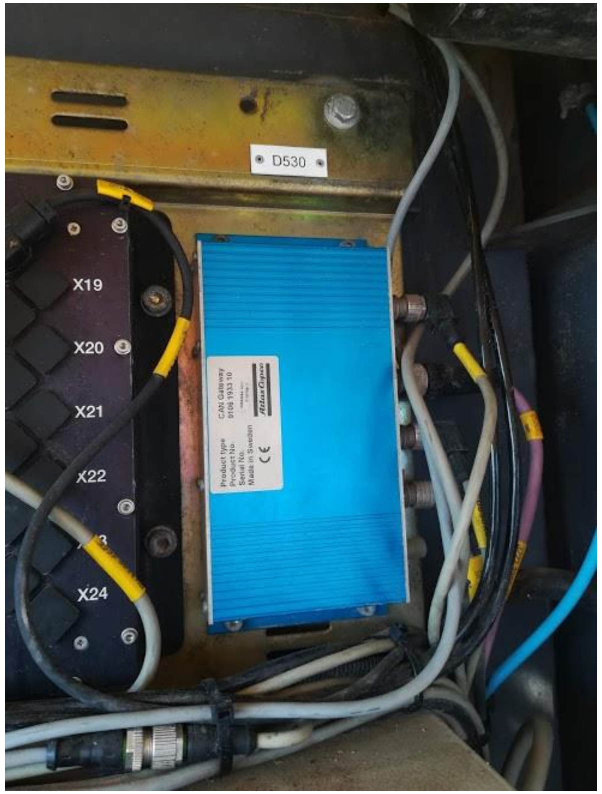


Management Platform



Trials and Evaluation

- Sine's seaport and Alto Tâmega dam



Trials and Evaluation

- Data availability from machines:

MachineValues	Remaining fuel	Ignition	Motor Consumption	Motor Temperature	Motor water Temperature	Oil Pressure	Tire Pressure	Motor Oil Temperature	Battery Potential	Battery Current
CAT d6t xl	No	Yes	No	No	No	No	Check	No	No	No
Texa Tool	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	No
cat 4 32	No	No	No	No	No	No	Check	No	No	No
atlas Copco roc d7	No	Yes	Yes	No	Yes	Yes	No	Invalid	Yes	Invalid
Wirtgen w100f road mining	Fuel Used	Yes	Yes	No	Yes	Yes	Check	Yes	Yes	Invalid
New Holland	Fuel Used	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Invalid

Open Issues

- J1939 information can be analyzed, converted, and presented through CAN bus sniffing. SAE standardizes J1939 parameters, however, **not all are implemented by manufacturers**

- Although some machines use standardized solutions at the protocol level, they **use plugs and/or connectors that do not conform with the standards**

- Integration of IIoT devices is possible and allows monitoring of the behavior of heavy machinery **if they use standardized protocols**. However big players such as CAT or Komatsu use proprietary protocols.

- Proprietary tools have competitive advantages but are an obstacle to the management of devices in heterogeneous environments.

- Design equipment to operate in harsh environments requires careful selection of components, physical device protection, and robustness tests.

Next Challenges

- Assembly prototype V2, and deploy 4 nodes in the field to continuous collect data from heavy machines in Alto Tamega Dam construction site
- Evaluate the performance of LoRaWAN vs LoRaWAN mesh to explore the mobility of the heavy vehicles on the construction site. Evaluate the performance of the solution
- From the data collected from the construction site, explore predictive ML models that can be used in the node and shared using federated learning to a main model
- Integrate the machine operational data in the company legacy information systems

Bibliography

[1] Aceto, G., Persico, V., & Pescapé, A. (2019). A Survey on Information and Communication Technologies for Industry 4.0: State-of-the-Art, Taxonomies, Perspectives, and Challenges. *IEEE Communications Surveys and Tutorials*, *21*(4), 3467–3501. https://doi.org/10.1109/COMST.2019.2938259

[2] A. Ghosh, D. J. Edwards, and M. R. Hosseini, "Patterns and trends in internet of things (iot) research: future applications in the construction industry," Engineering, Construction and Architectural Management, vol. 28, pp. 457–481, 2 2020.

[3] E. Sisinni, A. Saifullah, S. Han, U. Jennehag, and M. Gidlund, "Industrial Internet of things: Challenges, opportunities, and directions," IEEE Transactions on Industrial Informatics, vol. 14, pp. 4724–4734, 11 2018.

[4] Y. Zhang, Z. Guo, J. Lv, and Y. Liu, "A framework for smart production logistics systems based on cps and industrial IoT," IEEE Transactions on Industrial Informatics, vol. 14, pp. 4019–4032, 9 2018.

Thanks

Oscar Torres Sanchez
otorres@dei.uc.pt