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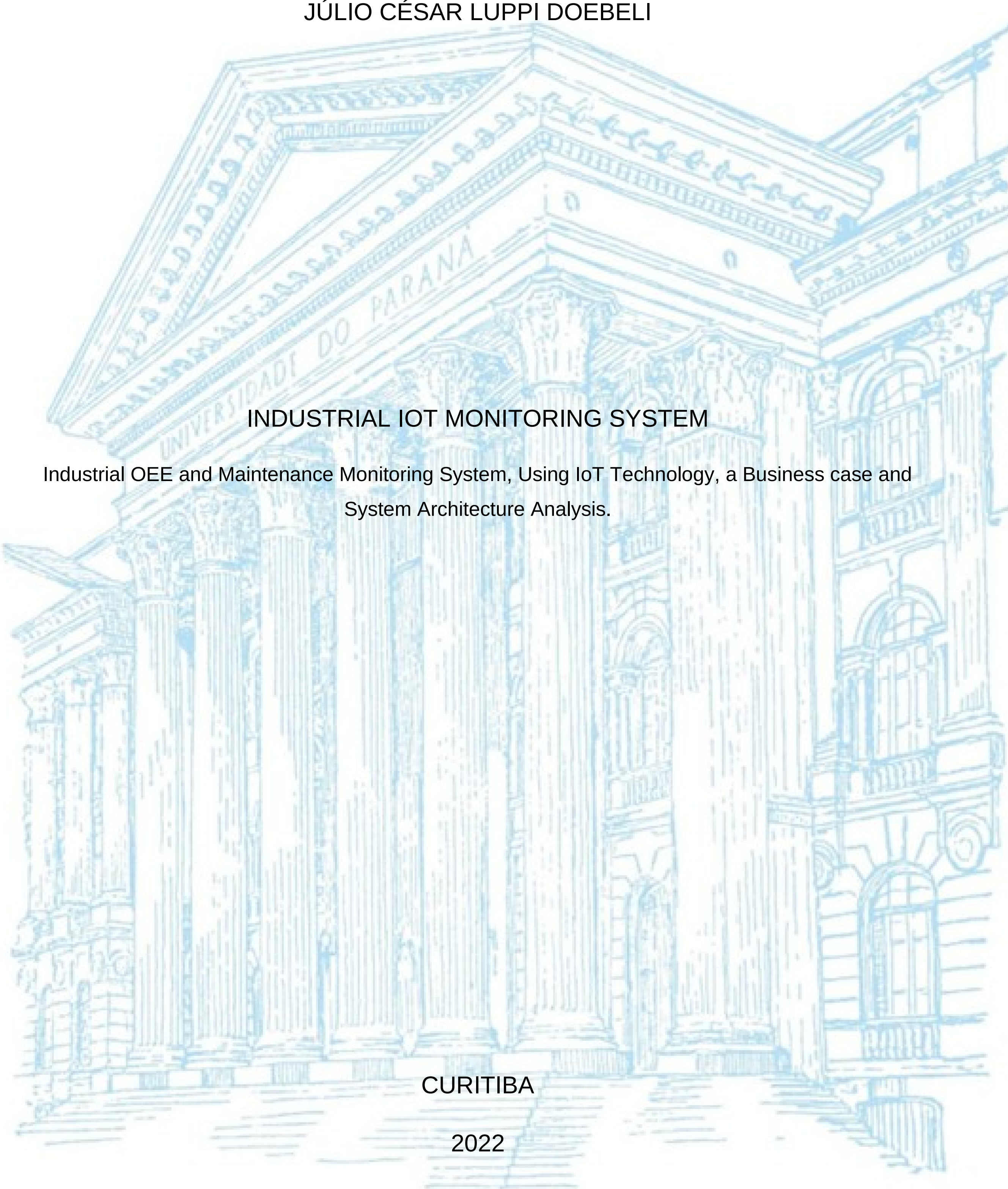

INDUSTRIAL IOT MONITORING SYSTEM

Industrial OEE and Maintenance Monitoring System, Using IoT Technology, a Business case and System Architecture Analysis.

CURITIBA

2022

JÚLIO CÉSAR LUPPI DOEBELI

INDUSTRIAL IOT MONITORING SYSTEM

Monografia apresentada como requisito parcial à obtenção do título de Bacharel, Curso de Ciência da Computação, Setor de Ciências Exatas, Departamento de. Informática, Universidade Federal do Paraná

Orientador: Prof. Eduardo Todt

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FOLHA/TERMO DE APROVAÇÃO

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Monografia aprovada como requisito parcial à obtenção do título de Especialista, Curso de Especialização em Gestão de Pessoas, Setor de Ciências Sociais Aplicadas, Universidade Federal do Paraná. Universidade Federal do Paraná, pela seguinte banca examinadora:

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A todos os colegas que contribuíram para a realização desse trabalho.

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Professora Elenice Novak

Avaliador Andrey Pimentel.

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The goal of this Theis is to respond the following questions: Is it possible to leverage IoT to improve industrial productivity? If so, is such a system commercially viable? What is the best system architecture for Large Telemetry data Ingestion and Processing? Are traditional metrics like OEE and MTBR still useful for increasing industrial productivity?

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1 – Industrial Computer Systems Timeline (Introduction)

Table 1 Computer Systems Timeline

1950s/ 1960s	MRP: Manufacturers develop basic **material** requirements planning systems PLC: Programable Logical Controllers	1955 **-** SCADA 1st Generation 1958 - Siemens Simatic PLC (Control.com technical articles plcs hardware history, 2022)
1970s	MRP-I: More manufacturers use MRP systems, first system providers founded. Databases: Relational Database Management System appear in the banking sector. (contel.com/ evolution of MES 'manufacturing execution systems', 2022)	1972 - SAP R/1 System RF (sap.com/ company history 1972-1980, 2022) 1974 - IBM’s System R Database (Berkeley.edu System R, 2022)
1980s	MRP-II: **Manufacturing** resource planning (MRP II) systems debut with more capabilities. SQL Databases: Structured Query Language and Relational Database Management System start to appear outside of banking sector. (Bright Work Research MRP II, 2022)	1986 - SQL-86 1972 - SAP R/2 ERP

1990s	ERP: Enterprise Resource Planning (ERP) systems debut, integrating all business functions (netsuite article erp history, 2022)	1990 - Gartner came up with the term "ERP" (Gartner Glossary ERP Enterprise Resource Planning, 2022)
2000s	Internet: Globally interconnected computer networks. Web Browser: Application software capable of HTTP, HTML and more.	Net Escape Vs. Internet Explorer (Browser Wars Documentary, 2022)
2010s	Cloud Server: Clusters of Computer Servers rented as a service. (projectpro article aws vs azure, 2022)	Amazon AWS Vs. Microsoft Azure
2020s	IoT: Internet of Things [1 2 3 4] Industry 4.0: 4th Industrial Revolution [1 2 3 4 5] Smart Home: [1 2 3 4] (Oracle what is IoT, 2022)	My Future Predictions

2 - Market and Feasibility study

2.1 - Market Situation

Industry 4.0 saves Brazil 73 billion BRL yearly.

Brazil might save R$ 73 billion with Industry 4.0. Industry 4.0 involves internet-connected machinery and equipment. Everything is real-time, even from different locations. AI, robotics, data analytics, and IoT collaborate. Brazilian Industrial Development Agency President Guto Ferreira says sensors monitor all activities remotely. AI generally maintains equipment. ABDI predicts R$35 billion in yearly repair savings. Saving R$31 billion on productivity. The rest is energy savings. Industry 4.0 decreases pollution. Process optimization can minimize CO2 emissions, says ABDI's president. Real-time monitoring of production results in a more sustainable, regulated operation with fewer unnecessary expenditures. Reduced resource use. ABDI and MDIC create Industry 4.0 in Brazil. Most industrial firms agree. "Introducing the techniques in the country assures companies to win overseas market," said Ferreira.

Effects and opportunities

In March 2018, the Ministry of Industry, Foreign Trade and Services will host WEF Latin America. (MDIC). The Forum will begin Brazil's fourth revolution, Industry 4.0. Paulo Skaf, president of Fiesp, remarked at ABDI's 1st Brazilian Congress of Industry 4.0 on December 5, 2017 that the change is daunting, but we must face and exploit its effects and opportunities. We must prepare and fortify ourselves, he urged. Skaf recalled fast changes. In 100 years, 20,000 years will pass. Students don't know the future of schooling. Be ready for employment losses and gains.

Detour

Brazil lags in Industry 4.0, says BNDES president Paulo Rabello de Castro. "We're behind. First, change direction. Industry 4.0 will affect education, health, safety, transit, logistics, culture, and consumption. We're also discussing traditional industrial needs and startup tech. ABDI created the National Startup Industry Connection Program, which is in version 4.0.

Study

Carlos Américo Pacheco, head of the So Paulo Research Foundation, said, "We must address market, infrastructure, and regulation" (Fapesp). Promotion and subsidy initiatives are inadequate in many businesses. He noted how institutions benefit businesses. Fapesp focuses on academic and technical research. Jorge Almeida Guimares, president of Emprapii, stated the firm has 42 divisions throughout Brazil. "One-third of these entities investigate advanced manufacturing," he added. Regional Finep supervisor Oswaldo Massambani says private R&D&I investment is important. "It's vital," he said. Without private investment, the government's help is insufficient.

Internet Of Things

Volkswagen's Powertrain Planning manager said others may follow. Culture must embrace Industry 4.0. All levels of the company must be trained and retrained. He stated Volkswagen is considering IoT. 73% of IoT initiatives fail. Reset mentality, start small and adopt a long-term plan, pick partners to assist lead the way, review company, develop, and focus on a limited number of IoT technologies. Unisys' Latin America VP says interoperability software is no longer industrial. "Open protocols are replacing proprietary ones for interoperability." Cyberattacks are more widespread, thus security must be everywhere. Teams need teamwork, expertise, and vulnerability. The CEO stressed that a company's security is constantly at stake. Beckhoff's general manager said a corporation must "produce properly." He claimed Industry 4.0 can't be hard, slow, or expensive. He recommended combining automation with IT. Industry 4.0 demands high performance, integrated functionality, IT integration, and an open automation platform.

Diplomacy

Israel Advanced Technology Industries CEO Karin Rubinstein said her country invests extensively in startups (startups). She stated Israel launches 500 new firms yearly. For Rubinstein, "creating an entrepreneurial and innovative culture and making a direct connection between the productive sector and academia and international partners can be the way to reach industry 4.0," he said, citing the MOU signed between IATI and ABDI during the Congress of Industry 4.0 to encourage advanced manufacturing partnerships between the two countries. South Korea's KIET president Byoung-Gyu Yu said Brazil should support micro and small firms. Small businesses may be lean, adaptive, and inventive. South Korea connects small and major businesses. Rainer Stark, head of Fraunhofer's Virtual Products Creation Division, said data collection and interpretation are vital to Industry 4.0. "Automation is useless. Good decision-making requires collecting, evaluating, and using information at the right time, he said, adding that the government and Brazilian firms must emphasize Industry 4.0 technology (ABDI research industry 4.0, s.d.).

2.2 - Technic and Economic Feasibility

Estonian company produces software, hardware to increase industrial production. Estonian company Evocon creates software to improve industrial production efficiency. EU funds helped it complete its cloud-based data logger. The technology allows customers visualize real-time production data and store data, allowing them to analyze efficiency and discover flaws. Plug-and-play data logger. Evocon provides online and phone support. Remote software updates, testing, and hardware troubleshooting are possible. Work on an environmental sensor began alongside the software. This is still in pilot phase because environmental considerations are not widely considered while optimizing production operations. Digitizing machine data has many benefits for companies. It helps companies to monitor order progress in real time and minimize overproduction, detect and eliminate production bottlenecks faster, and analyze production slowdowns to speed up procedures. Monitoring defects helps improve product quality. Real-time machine data improves reliability. Finally, management knows which areas need attention, leading to smarter investment selections. Digital methods have downsides. Installation is expensive since a team must set up and train workers on the system. On-premises monitoring frequently takes months to set up, and many manufacturers buy such devices based only on salesperson information, with no ability to assess if it satisfies their needs. Evocon wanted to eliminate superfluous costs, make monitoring systems completely functioning in days rather than months, and let clients test the system in their plants before investing.

https://ec.europa.eu/regional_policy/en/projects/Estonia/estonian-firm-develops-software-hardware-system-to-help-companies-boost-production

https://evocon.com/pricing/

Quick, cheap setup

Since launching the data logger alongside the cloud-based platform, Evocon's clients have praised the system's ease of use, with some able to set it up without contacting support. Customers get faster benefits with no implementation fees. The support team can remotely teach users, test, diagnose, and upgrade any Evocon device, anywhere in the world. Evocon can give a free trial of the system to any manufacturing company with an internet connection thanks to the data logger and software-as-a-service concept. It averages three monthly trials. It gives producers a comprehensive grasp of the product's benefits and Evocon's services. It eases firms' fears about digitizing machine data. Evocon benefits, too. The plug-and-play data logger and cloud-based applications have reached 44 countries. Between 2016 and 2018, its exports grew 323 percent. "Smart band-aid" predicts equipment failures. Tractian's AI analyzes device vibrations to predict breakage.

Broken machines cause multiple losses in industry. Add repair costs to production stoppage costs. Tractian, a 2019 startup, proposes a device that can be glued to equipment to identify breakage risks. Temperature and vibrations are analyzed. A platform displays AI-interpreted data. In it, you can monitor the machinery's "health" and, in cases of risk, how long it has left to work. So, the repair can be done early.

similar

Igor Marinelli and Gabriel Lameirinhas founded the startup. They met in computer engineering school and worked together. Somos Todos Heroes uses technology to allocate donations to sick children. Tractian was founded on another commonality. Parental maintenance supervisors. Igor Marinelli: "We talked a lot about industry because we saw our parents arrive late or stay overnight because of equipment problems." Marinelli used prediction technology before. In 2019, he won at Harvard & MIT's Brazil Conference for predicting chronic diseases. A visit to paper exporter Klabin clarified the industry's technological challenges.

Proof-of-concept

Marinelli and Lameirinhas suggested testing Tractian at one of the units. In 90% of cases, equipment problems could be predicted by interpreting vibration and temperature data. When they began market research, problems arose. The plant already had the measurement devices; it needed a platform to interpret them. But other industries were different. Marinelli: "We realized we could provide software and hardware." The two hired a developer and created the current model in the startup's So Paulo office (SP). They sold cars and invested R$40,000 to finance the project. They received R$50,000 in angel funding in March.

Strategy. Tractian wants R$100 per device. Small and medium-sized industries are the focus, as defined by their market experiences. "Despite being a small company, we speak directly with problem-solvers. Large companies are bureaucratic. Validating the solution and attracting companies' attention are top priorities. The startup has two paying customers and 50 devices. Angel investment helped prioritize free trials before commercialization. 100 sensors should be operational by July and 1,000 by year's end. The entrepreneur says the crisis has boosted customer interest. The solution reduces repair costs and remotely monitors machinery. "We shortened the sales cycle by six months." I don't know what will happen, but I think interest will linger." After growing 408% in 2021, Tractian raises BRL 80 million. With the investment, the company is worth over BRL 320 million. Tractian, a startup that monitors industrial systems, receives R$80 million from Next47. All previous investors participated, along with Totvs' CVC fund and Locaweb's Gilberto Mautner. The company is now worth over R$ 320 million. The startup tripled its customer base in 2021, including Embraer, Bosch, Danone, Hyundai, and John Deere. "This new investment will be crucial to consolidating our position in the global market, expanding our activities to new countries like Mexico, and strengthening the development of new products," says Tractian founder and co-CEO Igor Marinelli. In 18 months, the company plans to reach 600 new industries, 20,000 new sensors, and 200 employees. "We want to grow globally and in Brazil. Tractian is the right arm of maintenance for companies around the world "Gabriel Lameirinhas.

2.3 - Legal Feasibility

2.3.1 - General Data Protection Regulation (EU)

GDPR was adopted on April 14, 2016 and went into effect on May 25, 2018. The rule influenced Turkey, Mauritius, Chile, Japan, Brazil, South Korea, Argentina, South Africa, and Kenya to enact similar laws. The European Commission states that the law does not apply to "purely personal or domestic conduct." Before making decisions on data processing, the GDPR requires data controllers to assess the risks to individuals' rights and liberties. Article 15 is a right of the data subject. It provides access to personal data. A data controller must list categories of processed data. GDPR Article 20 guarantees data portability. Article 21 of the GDPR allows individuals to object to the processing of their personal data. The exercise of legal or governmental authority is occurring; The controller must communicate this immediately. Infringers of the GDPR face fines of up to €20 million or 4% of their global sales. Data controllers must design and implement data security by default. Article 25 mandates the incorporation of data protection into product and service development. Data subjects must be informed of data collection, legality of data processing, and automated decision-making. (gdpr.eu GRPD Vs LGPD, 2022)

Pseudonymization is a strategy for strengthening privacy that decreases the risks to data subjects. The EU Agency for Network and Information Security has published a report that describes how to safeguard privacy and data by default.

Controller records must contain the names and contact information of the controller, joint controller, controller's representative, and data protection officer. EU nations may alter these criteria. The records must include deletion timings for various data kinds. Data controllers must design systems with privacy in mind. Business operations involving the management of personal information must adhere to the principles. The European Data Protection Regulation requires data processors to implement data security measures (by pseudonymizing or anonymizing if needed). DPOs are analogous to officers of compliance. The DPO is responsible for managing IT systems, data security, and other critical business continuity issues involving personal and sensitive data. The processor must publish the contact details of the DPO. The law governs data processing and storage in the European Union. It applies to data controllers and processors outside the EU with "economic activity." The absence of a designated EU Representative demonstrates ignorance of the laws and procedures. This is in violation of the GDPR, which entails fines of up to €10 million or 2% of an organization's annual global sales. It will now be referred to as "UK GDPR." Under GDPR, the United Kingdom will not ban data transfers to EEA countries. Over 80% of IT specialists surveyed believe that GDPR-related expenditures would exceed $100,000 per business. It is anticipated that EU enterprises would spend €200 billion, while US corporations will spend $41.7 billion. GDPR is the most significant information policy law in a generation. Several businesses and websites amended their privacy policies and functions before to GDPR's implementation, resulting in a deluge of GDPR-related correspondence (dla piper data protection LGPD Article, 2022).

The Directive

The General Personal Data Protection Law (Brazil) 13709/2018 (LGPD) is a Brazilian privacy and data protection statute. The law consolidates forty Brazilian statutes governing the processing of personal data. The LGPD outlines the regulations and requirements for processing personal data of Brazilians, data acquired or processed in Brazil, and data used to sell products or services to Brazilians. The LGPD was signed into law on September 18, 2020, but enforcement started on August 16, 2020. On August 1, 2021, sanctions will commence. LGPD enforcement is the responsibility of the ANPD (Autoridade Nacional de Proteção de Dados).

2.3.1 - General Personal Data Protection Law (Brazil)

The LGPD defines personal data and sensitive personal data in Brazilian law in 65 articles. The law outlines the rights of individuals whose personal information is collected, processed, stored, and shared. It specifies the entity's responsibilities and the exceptions to the law. Article 18 of the LPGD allows data subjects to: verify data processing. To view their private details. To amend or rectify personal information. The anonymization, blocking, or deletion of unnecessary, excessive, or non-compliant personal data is required. To request a data controller to transfer personal data to a different vendor. Their personal information: To understand how personal data were shared. To be made aware of their right to refuse data processing. To revoke data processing consent.

Article 7 describes processing conditions for personal data: Allowance granted. To comply with the data controller's legal and regulatory obligations. For public administration and the implementation of statutes, rules, and contracts. Studies (anonymised where possible). Contractualize. Brazilian law. To ensure safety. To protect health, we require health professionals or sanitation workers. Unless it violates the subject's rights, for the data controller's or a third party's legitimate interest. Protection of credit rating Enforcement Article 48 of the LGPD requires the data controller to notify the national data protection authority and the data subject if a security incident poses a risk of damage or compromise to the data (as defined by ANPD). Article 52 specifies that the maximum LGPD fine is 2% of a company's Brazilian revenue, up to 50 million Brazilian reals. GDPR compare. The General Data Protection Regulation adopted by the EU in 2016 prompted the consolidation of data protection laws. The LGPD and GDPR contain the same data subject rights. As legal bases for data processing, the LGPD includes research and credit score maintenance. LGPD does not specify a timeframe for reporting data breaches, and its fines are less severe than GDPR's. (IAPP.org news Brazil effectuates privacy law immediately, 2022)

Timeline. In 2015, the Brazilian government drafted the Preliminary Draft Bill for the Protection of Personal Data and submitted it to Congress for debate and a vote. 14 August 2018 saw the passage by Congress of the General Personal Data Protection Act. On December 28, 2018, Michel Temer enacted interim measure 869 to amend the LGPD and establish the National Data Protection Authority (ANPD). The effective date of the LGPD has been pushed back to May 3, 2021, per measure 959. The lower house of Brazil's legislature revised the LGPD on August 26, 2020, to go into effect on December 31, 2020. The Federal Senate, the upper chamber of Brazil, ruled that any postponement was invalid because congress had already established the effective date. The LGPD was approved by the Senate on September 16, 2020, and signed the following day by Jair Bolsonaro. The LGPD entered into force on August 16, 2020 and became law on September 18, 2020. In August 2021, sanctions will take effect. (iapp.org news an Overview of Brazil's LGPD, s.d.)

2.4 - Operational Feasibility (Return on Investment)

The Brazilian industry has 303,600 businesses in 2020. These corporations made BRL 4 trillion in net sales income and paid BRL 308.4 billion in wages and other remuneration. This resulted in 7.7 million individuals working in the industrial sector. The Brazilian Institute of Geography and Statistics issued the PIA Empresa statistics today (21). (IBGE). The processing sectors accounted for 92.9% of industrial company revenue in 2020, according to the report. Food goods manufacturing had 24.1% of the Brazilian industry's net sales revenue. This industry grew 5.9 percentage points from 2011 to 2020, including 3.6 percentage points in 2019-2020. Motor vehicle, trailer, and body manufacturing, which was second in net sales revenue in 2011 and fourth in 2020, lost 4.9 percentage points in 10 years. Chemical products production rose from fourth to second in 10 years, achieving 10.5% of industry sales. Manufacturing coke, petroleum products, and biofuels (8.6%) and metallurgy (6.4%) remained third and fifth, respectively, between 2011 and 2020, the survey adds IBGE. (agenciabrasil.ebc.com.br economia noticia industrias emprego 7,7 milhões IBGE, 2022)

Labor, In 2020, manufacturing employed 97.4% of Brazil's 7.7 million workers. The five industries that employed the most workers in 2020 were food goods (23%), clothes and accessories (6.7%), metal (excluding machinery and equipment) (5.8%), motor vehicles, trailers, and bodywork (5.7%), and non-metallic mineral products (5.3%). According to the IBGE, the industry cut its employment by 1 million employees between 2011 and 2020, focusing on sectors projected to suffer more significant structural changes due to technology, foreign competition, and domestic demand. Between 2011 and 2020, more than half of the loss was concentrated in apparel and accessory manufacturing (258.4 thousand), leather preparation and manufacturing of leather goods, travel items and footwear (138.1 thousand), and manufacturing of metal products, except machinery and equipment (134.2 thousand). In 2020, 35,241 jobs were added (a 0.5% increase), with 80% in manufacturing. Food products manufacturing added 121.5 thousand jobs throughout the time.

The biggest challenge to operate a IoT Telemetry company is having enough monthly subscribers to support the business. The number of subscribers is directly proportional to the number of machines with an operator. And the number of machines with an operator is proportional to the 7.7 million total number of Employees. If we assume the worst case where:

- All industries work on tree shifts
- Only 35% of industrial workers operate some machine
- All Industries except automotive are viable clients (95%)
- Early adopters correspond also known as easy clients available for acquisition correspond to 1% of total market

That would mean an estimate 768 thousand machines total market cap available to become monthly subscribers and 7,6 thousand early adopters in Brazil. Considering that the World's Industrial GDP is 38,340,000 and Brazil's Industrial GDP is 672,336 (in million USD in 2017). Meaning that Brazil corresponds to 1.75% of industrial output. Extrapolating from this information it is possible to estimate 44 million machines total market cap available to become monthly subscribers and 440 thousand early adopters in worldwide. Considering a monthly subscription price of 100 USD/Month and including the ten biggest countries in the analysis results in the following table:

Table 2 IoT OEE Market Capitalization

Country/Economy	Industrial GDP (in millions of USD)	Industrial GDP %	Machine OEE Iot Market CAP Estimate (in millions of USD)	Machine OEE Iot Early Adopter Estimate (in millions of USD)
World	38.340.000	100,0%	4.380	43,80
China	9.400.050	24,5%	1.074	10,74
United States of America	3.722.590	9,7%	425	4,25
India	2.179.020	5,7%	249	2,49
Japan	1.638.343	4,3%	187	1,87
Germany	1.289.093	3,4%	147	1,47
Russian Federation	1.301.184	3,4%	149	1,49
Indonesia	1.332.500	3,5%	152	1,52
Brazil	672.336	1,8%	77	0,77

(cia.gov world factbook GDP per country, 2020)

2.5 - Timing Feasibility (Innovation adoption curve)

Gartner's hype cycle is a graphical representation of the maturity, acceptance, and societal applicability of various technologies. The hype cycle purports to give a graphical and conceptual representation of the five stages of technological maturation. The model is not perfect, and research indicates that some improvement could be made. The hype cycle is built on the same idea as the Dunning–Kruger effect, which applies to people's belief in their talents rather than the visibility of technology. (Researchgate.net publication 224182916_Scrutinizing_Gartner's_hype_cycle_approach, 2022)

1-Technology Event: A prospective technological breakthrough initiates proceedings. Early reports of proof-of-concept and media attention generate tremendous exposure. Frequently, there are no useful goods and the commercial feasibility is untested.

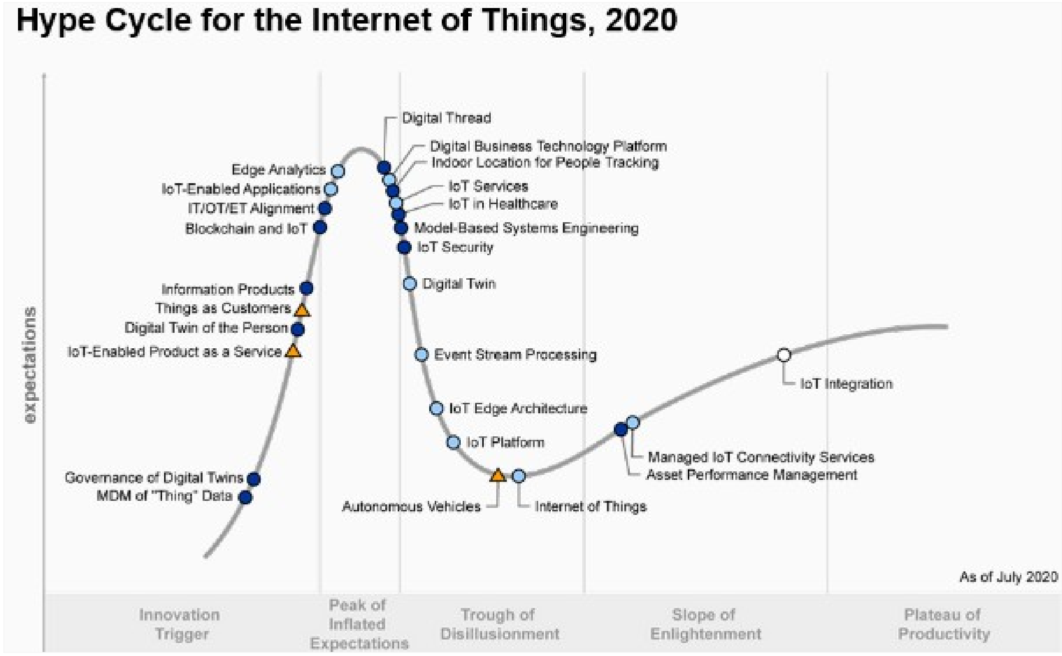
2-Excessively High Expectations: Early publicity creates a lot of success stories, which are frequently accompanied by a large number of failures. Some businesses take action, but the majority do not.

3-Pit of Disillusionment: As experiments and implementations fail to deliver, interest wanes. Or producers of the technology will fail. Only if the surviving vendors enhance their offerings to the delight of early adopters will investment continue.

4-Slope of Illumination: More examples of how the technology might aid the business begin to solidify and become broadly known. Technology vendors release second- and third-generation products. More enterprises fund pilots; conservative companies remain wary.

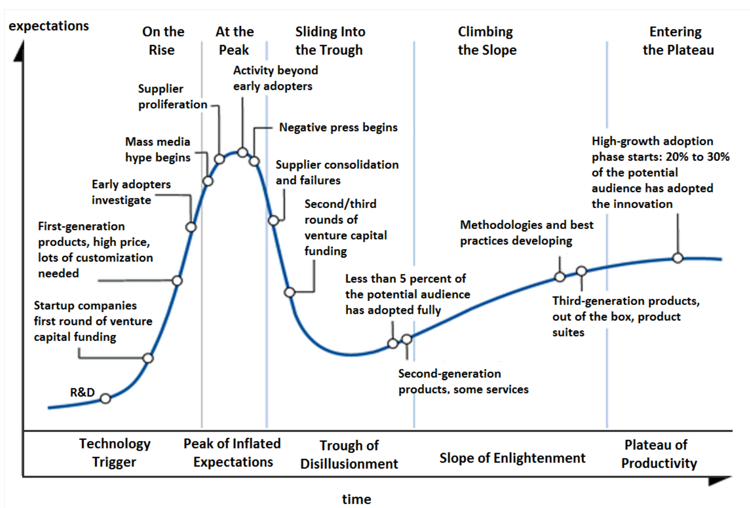
5-Level of Productivity: Adoption in the mainstream begins to take momentum. The criteria for evaluating the feasibility of a service are more precisely stated. The broad market application and usefulness of the technology are definitely paying off. If the technology has a market that is larger than a niche, it will continue to expand. (Lessons from 20 years of hype cycles by michael mullany, 2022)

Figure 1 IoT Hype Curve



(wired.com IoT Hype Curve, s.d.)

Figure 2 Technology Hype Curve



(technology-hype-curve, 2022)

3 - OEE, TEEP and MTBF

3.1 - What Exactly Is OEE?

OEE (Overall Equipment Efficiency) is the gold standard for measuring manufacturing productivity. Simply expressed, it represents the proportion of manufacturing time that is actually productive. A 100% OEE score indicates that you are producing only Good Parts as quickly as possible with no Stop Time. 100% Availability (no Stop Time), 100% Performance (as quick as feasible), and 100% Quality (only Good Parts).

Figure 3 OEE FACTORS (from oee.com)

Equation 1 OEE

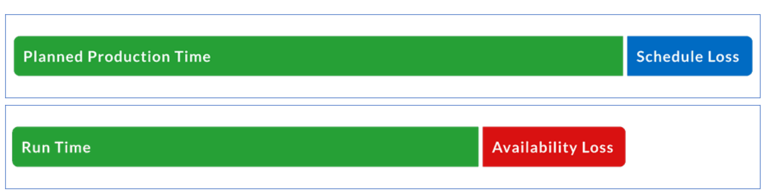
$$OEE = (Availability)\, x\, (Performance)\, x\, (Quality).$$

OEE measurement is an industry best practice. By evaluating OEE and underlying losses, companies receive valuable insights about how to consistently enhance their manufacturing process. OEE is the most effective indicator for discovering losses, comparing progress, and enhancing the productivity of industrial equipment (i.e., eliminating waste). Your OEE score indicates where you are, but the three underlying elements (Availability, Performance, and Quality) indicate where you should concentrate your efforts for improvement. (https://www.oee.com/teep/, 2022)

3.2 - OEE Availability

Availability accounts for Availability Loss, which includes any occurrences that halt planned output for a substantial amount of time (usually several minutes; long enough for an operator to log a reason). Unplanned Stops (such as equipment failures and material shortages) and Planned Stops are examples of instances where Availability Loss occurs (such as changeover time). OEE analysis includes changeover time because it is time that could otherwise be employed for manufacturing. While it may not be able to remove changeover time entirely, it is typically possible to cut it greatly.

Figure 4 6 OEE Availability (from oee.com/oee-factors/)



Equation 2 Availability

$$Availability = (Run\, Time) / (Planned\, Production\, Time).$$

When defining the Produce Count, the Availability percentage and the time period must always be accounted for. If not, the Ideal and Real production counts will be incompatible, and the resulting calculation would be incorrect. (https://www.oee.com/oee-factors/, 2022)

3.3 - OEE Performance

Performance includes Performance Loss, which accounts for anything that causes a manufacturing process to run slower than its maximum feasible speed when it is operating (including both Slow Cycles and Small Stops). Indicators of Performance Loss include machine wear, inferior materials, misfeeds, and jamming. The time remaining after subtracting Performance Loss is known as Net Run Time.

Figure 5 OEE Performance (oee.com/oee-factors/)

Equation 3 Performance

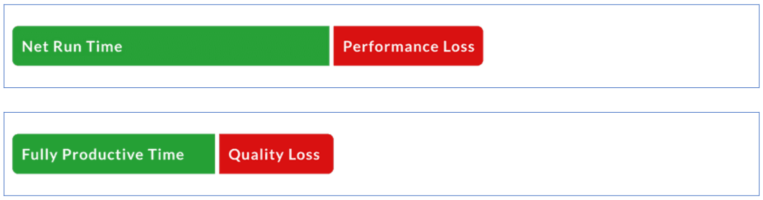
$$Performance = (Actual\ Product\ Count)/(Ideal\ Product\ Count).$$

When establishing the Ideal Produce Count, the Availability percentage and the time period must always be considered. If not, the Ideal and Real production counts will be incompatible, and the resulting calculation would be incorrect.

3.4 - OEE Quality

Quality takes Quality Loss into account, which accounts for manufactured components that do not fulfill quality standards. Examples of things that contribute to Quality Loss include scrap and reworked parts. Similar to First Pass Yield, OEE Quality defines Good Parts as those that successfully complete the manufacturing process on the first attempt without requiring rework. Fully Productive Time is the time remaining after Quality Loss has been deducted. Our objective is to maximize Fully Productive Time, to calculate OEE.

Figure 6 OEE Quality (oee.com/oee-factors/)



Equation 4 Quality

$$Quality = (Number\ of\ Good\ Products)/(Total\ Number\ of\ Products).$$

3.5 - What Is TEEP?

The Overall Equipment Effectiveness (OEE) exposes how much of your Planned Production Time is actually productive, while the Total Equipment Effectiveness Potential (TEEP) shows how much potential you have to boost throughput with the equipment you now own. TEEP (Total Effective Equipment Performance) is a performance statistic that reveals your manufacturing operation's full capabilities. It takes both Equipment Losses (as measured by OEE) and Schedule Losses into consideration (as measured by Utilization). Let's compare OEE and TEEP briefly: OEE estimates the proportion of PPT that is actually productive. TEEP quantifies the proportion of All Time that is productive. If your TEEP score is 100 percent, then you are producing solely Good Parts as quickly as possible, nonstop (24/7). In other words, neither Schedule Losses nor OEE Losses exist.

Figure 7 TEEP Utilization (oee.com/oee-factors/)

Equation 5 Utilization

$$Utilization = Planned\ Production\ Time / All\ Time$$

Equation 6 TEEP

$$TEEP = OEE\ x\ Utilization.$$

3.5 - The Six Big Losses

One of the primary objectives of TPM (Total Productive Maintenance) and OEE programs is to decrease and/or eliminate productivity loss. Now that you are familiar with the definitions of OEE, TEEP and their four factors. We can define the six big productivity losses and examine the relationship between each big loss and factor.

3.5.1 - EQUIPMENT FAILURE

Equipment Failure accounts for any considerable amount of time that production-scheduled equipment is not operating owing to a failure of any kind. A broader definition of equipment failure is any unanticipated stoppage or downtime. Equipment Defects Constitute Availability Losses. Common causes of Equipment Failure include defective tools, malfunctions, and unscheduled maintenance. In the broader context of unscheduled stoppage, shortage of personnel or materials, being starved by upstream equipment, or being blocked by downstream equipment are also common causes.

It is possible to adjust the threshold between Equipment Failure (an Availability Loss) and a minor interruption (a Performance Loss). For tracking purposes, a decent rule of thumb is to establish this level depending on your policy. For instance, your policy may stipulate that any downtime lasting longer than two minutes must be accompanied by an explanation and is therefore considered Equipment Failure.

3.5.2 - SETUP AND ADJUSTMENTS

Setup and Adjustments accounts for any considerable periods of time during which production-ready equipment is not operating owing to a changeover or other equipment adjustment. Setups & Adjustments can be thought of more generally as any scheduled pause. Setup and Adjustments are a Loss of Availability. Setup, changeovers, major adjustments, and tooling adjustments are typical examples of prevalent Setup and Adjustments causes. In the broader context of planned stops, cleaning, warmup time, planned maintenance, and quality inspections are also common reasons. Changeovers (also known as make ready or setup) are often the largest contributor to Setup and Adjustment time, which can be reduced with good scheduling of operation change.

3.5.3 - IDLING AND MINOR STOPS

Idling and Minor Stops represents the time when the equipment stops for a brief amount of time (usually less than two minutes) and the operator resolves the stop. Small stops are another name for Idling and Minor Stops. Idling and Minor Stops are Detrimental to Performance. Misfeeds, material jams, obstructed product flow, wrong settings, misaligned or obstructed sensors, equipment design faults, and periodic fast cleaning are prominent examples of Idling and Minor Stops. This category typically comprises stops that require no maintenance workers and last significantly less than five minutes. Frequently, the underlying problems are chronic (same problem, different day), which might render operators oblivious to their influence. The majority of businesses do not accurately monitor Idling and Minor Stops.

3.5.4 - REDUCED SPEED

Reduced Speed represents the time in which equipment operates slower than the Ideal Cycle Time (the theoretical fastest possible time to manufacture one part). Slow cycles is an alternative term for slower pace. Decreased velocity is a Performance Loss. Common causes of decreased speed include soiled or worn-out equipment, inadequate lubrication, bad materials, poor ambient conditions, operator inexperience, startup, and shutdown. This category consists of anything that prevents the process from running at its theoretical maximum speed (also known as Ideal Run Rate or Nameplate Capacity) when the manufacturing process is in operation.

3.5.4 - PROCESS DEFECTS

During stable (steady state) production, damaged parts are attributed to Process Defects. This comprises both scrap pieces and those that can be reworked, as OEE gauges quality based on First Pass Yield. Process flaws constitute a Quality Loss. Common causes of process defects include improper equipment settings, operator or equipment handling errors, and expiration of the lot (e.g., in pharmaceutical plants).

3.5.5 - REDUCED YIELD

Reduced Yield compensates for defective items generated from startup until production reaches steady-state (steady-state production). This comprises both scrap pieces and those that can be reworked, as OEE gauges quality based on First Pass Yield. Reduced Yield can occur after the start-up of any piece of equipment; however, it is most typically observed during changeovers. Decreased yield is a loss of quality. Common causes of Reduced Yield include poor changeovers, wrong settings when a new part is operated, equipment that requires warmup cycles, and equipment that creates waste immediately after commencement (e.g., a web press).

3.5.6 - USING THE SIX BIG LOSSES

Using the Six Big Losses paradigm provides a clear roadmap for enhancing OEE. Working to limit Availability Loss as a result of Equipment Failures or Setups and Adjustments safeguards against avoidable unplanned pauses or downtime and minimizes planned stops. Addressing the Performance Loss caused by Idling, Minor Stops, and Reduced Speed minimizes the accumulation of minor stops and slow cycles. Lastly, limiting Quality Loss in the form of Process Defects and Reduced Yield decreases the quantity of useless components generated before to and during steady-state manufacturing. In total, the Six Big Losses identify and classify problems that manufacturers encounter on a daily basis. Consistently working within this framework to address one loss at a time will result in an OEE score that is consistently improving.

OEE Quality is similar to First Pass Yield in that it defines Good Parts as those that pass through the manufacturing process without requiring rework on the first attempt.

3.5.7 - COMPARISON OF SIMPLE VERSUS PREFERRED OEE CALCULATION

OEE can be determined using the following formula: OEE = (Actual Production) / (Planned Production Time) / (Max Production Speed). Where Max Production Speed is measured in units per time and Good Parts are produced as quickly as possible. Although this is a perfectly accurate computation of OEE, it does not account for the three loss-related aspects of Availability, Performance, and Quality. We utilize the preferred calculation for this purpose.

OEE ratings offer extremely significant knowledge - a precise picture of how efficiently your manufacturing process is operating. Additionally, it facilitates the tracking of process improvements over time. Your OEE score does not provide any information regarding the root causes of lost productivity. Availability, Performance, and Quality play this function. In the chosen computation, the best of both worlds are obtained. A single figure that quantifies your performance (OEE) and three values that quantify the nature of your losses (Availability, Performance, and Quality).

3.6 - Remembrance of The Founder of TPM

Total Productive Maintenance (TPM) was developed for the first time in 1969 at Nippon Denso Co. (now Denso Corp., Kariya, Aichi Prefecture, Japan), a subsidiary of Toyota Motors, under the direction of Mr. Seiichi Nakajima of the Japan Institute of Plant Maintenance (JIPM), Tokyo. During the following decade, TPM was further developed and polished in Japan, and by the mid-1980s it had reached the United States. Mr. Nakajima, the "Father of TPM" who brought us his impassioned vision and methods, passed away on April 11, 2015 at the age of 96.

A lifetime of effort.

Mr. Nakajima spent over fifty years as a maintenance consultant and TPM instructor. During the reconstruction of Japan following World War II, he studied maintenance techniques in the United States. In 1951, after studying preventative maintenance in the American approach, Mr. Nakajima brought Productive Maintenance (PM), the precursor of TPM, to Japan. (efficientplantmag.com/2015/06/remembering-the-father-of-tpm/, 2022)

JMA Consultants Inc. (associated with the JIPM), Englewood Cliffs, NJ, stated in a news release announcing Mr. Nakajima's death, "Without his amazing effort, TPM and the manufacturing industry would not be what they are today." His founding of the PM Awards (now the TPM Awards) was cited as one of his most notable accomplishments. Denso was the first recipient of the PM Awards with TPM methodology in 1971, the year generally regarded as the start of TPM. Mr. Nakajima's accomplishment was also recognized by the Emperor of Japan, who decorated him with the Ranju Ho-sho, or Blue Ribbon Medal. The Emperor presented Mr. Nakajima with this honor, which acknowledges major lifetime accomplishments, "to express his appreciation for his effort to enhancing the manufacturing industry through TPM."

Toyota Manufacturing System

The renowned Toyota Production System (TPS) and other important Japanese industrial strategies owe a great deal to Mr. Nakajima and the TPM. Taiichi Ohno, who invented TPS and Kanban in the 1970s, and Shigeo Shingo, a Toyota industrial engineer in the 1960s and 1970s who contributed to TPS (and other techniques), have recognized Mr. Nakajima for his pioneering work in decreasing equipment malfunctions. Shingo wrote in 1981's A Study of the Toyota Production System, "To approach the ideal of non-stock production [single-piece flow], remove breakdowns and defects by identifying and addressing their causes." (https://oee.academy/oee-academy/history-of-oee-and-tpm/, 2022)

And in Toyota Production System (1978), Ohno remarked, "Toyota's strength is not derived from its healing process; rather, it is derived from preventive maintenance." Ohno and Shingo recognized that Total Productive Maintenance (TPM) was the solution for eliminating equipment-related waste (or losses) and achieving the aim of uninterrupted production flow, which could not be addressed by traditional maintenance procedures. Seiichi Nakajima shown repeatedly that TPM is the equipment component of TPS (and lean manufacturing). Unfortunately, many "lean thinkers" of today neglect Mr. Nakajima and his TPM concepts when adapting the TPS principles to their travels toward continuous improvement.

(https://web.archive.org/web/20160304221739/http://tpm.jipms.jp/nprize/#2009, 2022)

Words of knowledge:

During my TPM learning curve, Seiichi Nakajima gave me with numerous pearls of wisdom:

• "Just-in-time manufacturing, Toyota's Production System, is impossible without TPM. "Uninterrupted flow, higher quality, less waste, and cheaper costs are the results of equipment that is free of problems."

• "According to the system's founder, Taiichi Ohno, the Toyota Production System is predicated on the elimination of all waste. TPM is designed to eliminate the six major losses. This corresponds to the Toyota Production System's complete elimination of waste. TPM emphasizes defect-free production, just-in-time production, and automation in the pursuit of zero breakdowns. Without TPM, it is safe to state that the Toyota Production System could not function." 1

• "Maximizing the efficacy of equipment demands the removal of all failures, faults, and other negative occurrences, or the wastes and losses associated with equipment operation."

• "TPM evolved from the principles of 'American-style preventive maintenance' in the 1950s, 'Japanese-style productive maintenance' in the 1960s, and the principles of 'Total Quality Management' and'small-group problem resolution' in the 1960s as well."

• "TPM is not an upkeep program. TPM is a company-wide program for enhancing the effectiveness of equipment, something maintenance alone could not do. When TPM arrived in the United States, we recognized we probably misnamed it Total Productive Maintenance. Should have probably been Total Productive Manufacturing."

• "Americans will have difficulty implementing TPM because they anticipate that equipment will break down and that the maintenance team will fix it." In many companies, the objective of "zero equipment breakdowns" is met with skepticism and even denial. Yet, these same businesses set goals of zero faults and zero accidents.

• "The word 'Total' in Total Productive Maintenance has the following meanings: total effectiveness—the pursuit of economic efficiency or profitability; total PM—maintenance prevention and activity to improve maintainability in addition to preventive maintenance; and total participation—autonomous maintenance by operators and small group activities in every department and at every level." 2

• Regarding the TPM Pillars: "Culturally, the Japanese and the Americans are very different: Japan has historically been a highly interdependent nation and culture, whereas the Americans are highly independent. The TPM Pillars are interconnected in that they rely on one another rather than being independent."

• "Overall Equipment Effectiveness (O.E.E.) percentages should only be used to compare equipment to itself over time; they should never be used to evaluate other types of equipment or equipment operating on different goods."

Mr. Nakajima, thank you for laying the groundwork for what will likely be the most strategic approach to equipment maintenance for the foreseeable future.

3.7 - OEE Improvement Simulation

My OEE Improvement Simulation follows the subsequent preconditions and definition:

- Low efficient company means OEE around 27% and is the base case for analysis (this is in accordance to ADBI research).
- High Efficiency is 85% OEE as defined by Seiichi Nakajima in TPM (Total Productive Maintenance) original book.
- Medium Efficiency is the geometric average between Low and High Efficiency (48%).

- Global Market segment of the company is not saturated, meaning that if they produce more almost all production will be sold around the same price.
- Total production cost is sum of fixed cost, plus variable cost.
- Total production cost is one million dollars for base case (low efficiency).
- Revenue after tax deduction is Total production cost plus 10%.
- Net Profit is Sales price after tax deduction minus total production cost.
- Five examples are used:
    - 90% fixed cost - 10% variable cost
    - 70% fixed cost - 25% variable cost
    - 50% fixed cost - 50% variable cost
    - 75% fixed cost - 25% variable cost
    - 90% fixed cost - 10% variable cost

Table 3 OEE Improvement Simulation (according to my simulation)

90% Fixed Cost - 10% Variable Cost			
Indicator	Low Efficiency	Medium Efficiency	High Efficiency
OEE %	27%	48%	85%
Fixed cost	$ 900.000	$ 900.000	$ 900.000
Variable cost	$ 100.000	$ 177.430	$ 314.815
Total production cost	$ 1.000.000	$ 1.077.430	$ 1.214.815
revenue afther tax deduction	$ 1.100.000	$ 1.951.732	$ 3.462.963
Net Profit	**$ 100.000**	**$ 874.302**	**$ 2.248.148**
Improvement		774%	2148%

75% Fixed Cost - 25% Variable Cost			
Indicator	Low Efficiency	Medium Efficiency	High Efficiency
OEE %	27%	48%	85%
Fixed cost	$ 750.000	$ 750.000	$ 750.000
Variable cost	$ 250.000	$ 443.576	$ 787.037
Total production cost	$ 1.000.000	$ 1.193.576	$ 1.537.037
revenue afther tax deduction	$ 1.100.000	$ 1.951.732	$ 3.462.963
Net Profit	**$ 100.000**	**$ 758.157**	**$ 1.925.926**
Improvement		658%	1826%

50% Fixed Cost - 50% Variable Cost			
Indicator	Low Efficiency	Medium Efficiency	High Efficiency
OEE %	27,0%	47,9%	85,0%
Fixed cost	$ 500.000	$ 500.000	$ 500.000
Variable cost	$ 500.000	$ 887.151	$ 1.574.074
Total production cost	$ 1.000.000	$ 1.387.151	$ 2.074.074
revenue afther tax deduction	$ 1.100.000	$ 1.951.732	$ 3.462.963
Net Profit	**$ 100.000**	**$ 564.581**	**$ 1.388.889**
Improvement		465%	1289%

25% Fixed Cost - 75% Variable Cost			
Indicator	Low Efficiency	Medium Efficiency	High Efficiency
OEE %	27,0%	47,9%	85,0%
Fixed cost	$ 250.000	$ 250.000	$ 250.000
Variable cost	$ 750.000	$ 1.330.727	$ 2.361.111
Total production cost	$ 1.000.000	$ 1.580.727	$ 2.611.111
revenue afther tax deduction	$ 1.100.000	$ 1.951.732	$ 3.462.963
Net Profit	**$ 100.000**	**$ 371.006**	**$ 851.852**
Improvement		271%	752%

10% Fixed Cost - 90% Variable Cost			
Indicator	Low Efficiency	Medium Efficiency	High Efficiency
OEE %	27,0%	47,9%	85,0%
Fixed cost	$ 100.000	$ 100.000	$ 100.000
Variable cost	$ 900.000	$ 1.596.872	$ 2.833.333
Total production cost	$ 1.000.000	$ 1.696.872	$ 2.933.333
revenue afther tax deduction	$ 1.100.000	$ 1.951.732	$ 3.462.963
Net Profit	**$ 100.000**	**$ 254.860**	**$ 529.630**
Improvement		155%	430%

3.8 – MTBF and MTTR

Mean time between failures (MTBF) is the average amount of time between system failures. Together, MTBF and MTTR are used to calculate availability. The MTBF calculation takes into account only unscheduled maintenance and disregards regular maintenance, such as inspections and recalibrations.

The MTBF is used to predict how likely an asset is to fail within a specified time period or how frequently a particular form of failure may occur. An MTBF study helps your maintenance staff decrease downtime, save money, and increase productivity. This information facilitates the creation of PMs, hence enhancing dependability.

Knowing the failure frequency of an asset enables you to organize preventive maintenance in advance. By analyzing your work order data, you may identify and eliminate the core cause of a particularly consistent failure. This strategy is a step in the direction of condition-based maintenance. Additionally, you may monitor MTBF for a particular failure.

The MTBF of an asset provides a benchmark for optimizing your preventive maintenance program. Knowing the failure frequency of an asset enables you to organize preventive maintenance in advance. This provides you a greater chance of preventing failure while performing the least amount of maintenance feasible and maximizing your resources. This strategy is a step in the direction of condition-based maintenance. Additionally, you may monitor MTBF for a particular failure. Not only can you target this failure using PMs, but you can also explore why a particular issue is causing a reduced MTBF. The culprit may be an imprecise work list, a malfunctioning item, or insufficient training. By analyzing your work order data, you may identify and eliminate the core cause of a particularly consistent failure. (https://www.fiixsoftware.com/maintenance-metrics/mean-time-between-fail-maintenance/, 2022)

The MTTR formula is derived by dividing the total unscheduled maintenance time spent on an asset by the total number of failures that asset suffered within a given time period. Mean repair time is most frequently expressed in hours. (https://www.fiixsoftware.com/maintenance-metrics/mean-time-to-repair-maintenance/, 2022)

Equation 7 MTBF (Mean Time BetweenFailures)

$$MTBF = N° \, of \, Operational \, Hours \div N° \, of \, Failures$$

Equation 8 MTTR (Mean Time To Repair)

$$MTTR = N° \, of \, Maintenance \, Hours \div N° \, of \, Failures$$

About the reference: Measures mean time to failure (MTTF) and mean time between failures (MTBF) are often used interchangeably. MTBF is understood to be the universal attribute of a non-repairable item, while MTTF is often assumed to be an indicator of the expected life of that item. The paper discusses the often-inaccurate applications and gross misinterpretation of the terms MTBF and MTTF. It emphasizes that one item does not have and cannot have one MTBF or MTTF, but those, if calculated, averaged, estimated, are entirely and widely dependent on the application stresses. (How to estimate and use MTTF/MTBF would the real MTBF please stand up? 4914702, 2009)

4 - Distributed System Network and Data Flow

4.1 - System Architecture

A **IoT Smart Sensor and IoT Monitor Combo** is a device that collects input from the machine and its surroundings and uses on-board computer capabilities to perform predefined actions upon detecting certain input before processing and delivering data. Smart sensor/monitor provide more accurate and automated industrial data collection, with less erroneous information mixed in with the proper data. These devices are used to monitor equipment in a variety of industrial applications. The smart sensor is also an essential component of the internet of things (IoT), a world in which practically anything imaginable may be outfitted with a unique identity and the ability to transfer data over the internet or a similar network.

The **Edge Computer** creates a streamlined and clean flow of data between the IoT Smart Sensor/Monitor and The Fog Server, which alleviates Fog server overhead. At the same time, users will enjoy much faster performance as the response time of an on-premises Fog Server with Cloud Cluster Backup is significantly reduced.

Figure 8 Components Overview (my system architecture)

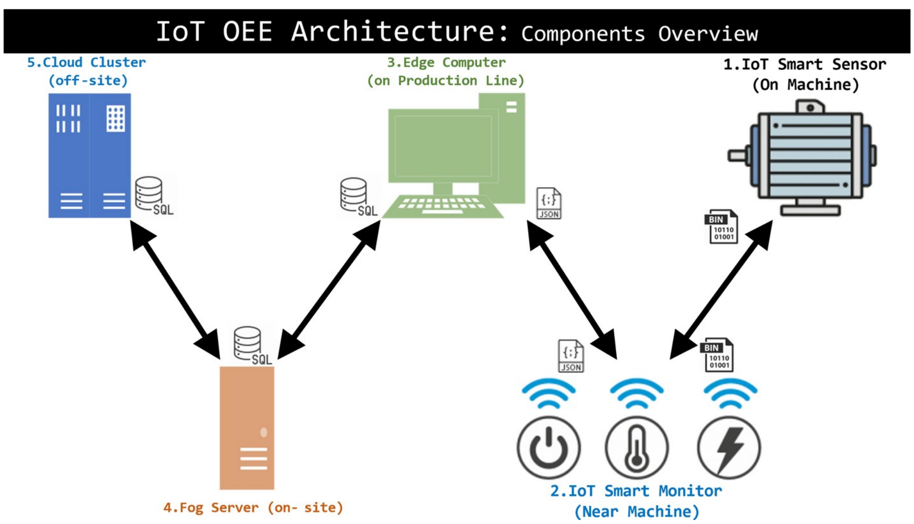
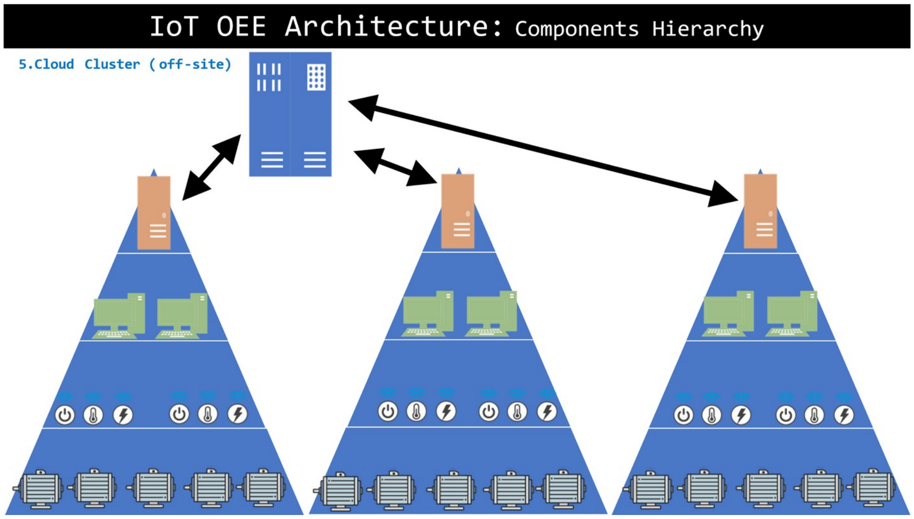
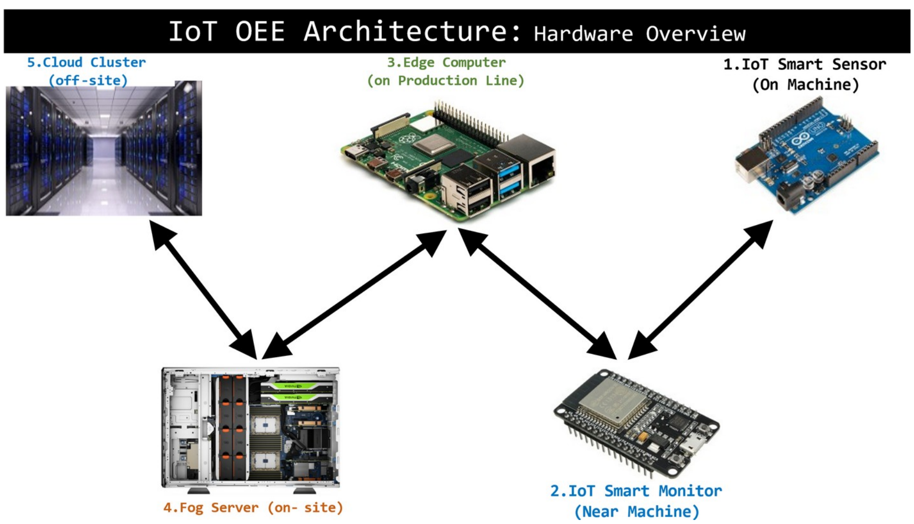


Figure 9 Components Hierarchy (my system architecture)



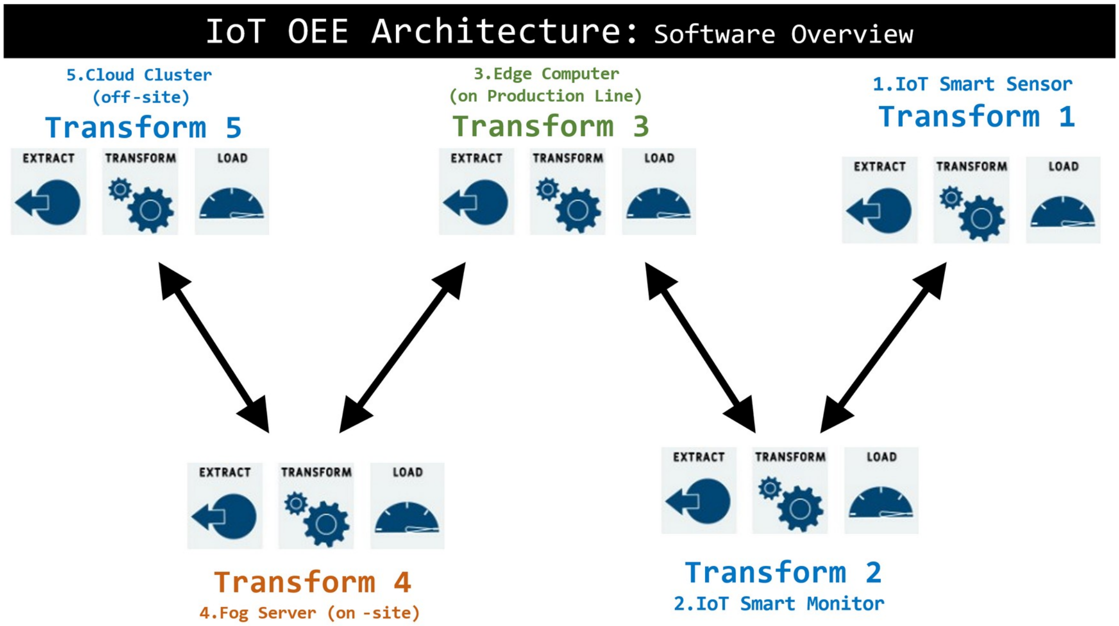
There is 1 Fog Server for each client and one Edge Computers for every 15 machines. Each Machine has one IoT Monitor and 13 Smart Sensors. For example, if an industry has 240 machines they will need 1 Fog Server, 16 Edge Computers, 240 IoT Smart Monitors and 3.120 Smart Sensors.

Figure 10 Hardware Overview (my system architecture)



From the 1st until the 4th the processing power and storage capacity approximately ten folds per individual component. But the number of individuals per layer drops by a factor of more than ten meaning that the layer with more processing power is the Sensor Layer and the second most powerful is the Monitor Layer.

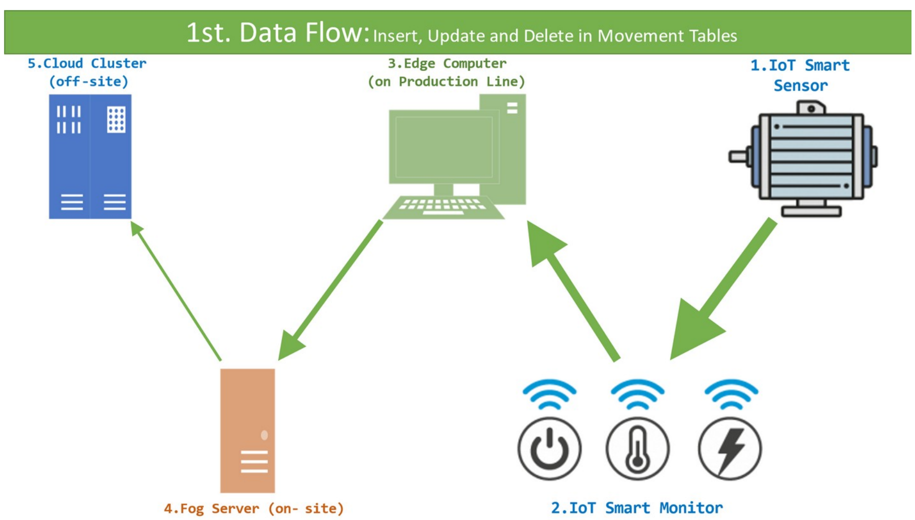
Figure 11 Software Overview (my system architecture)



On a High Level each component is very similar because all of them mainly execute a ETL Workload. In This case ETL means Extract Transform and Load. The main difference is the scope of the ETL being executed.

4.1 - Data Flows

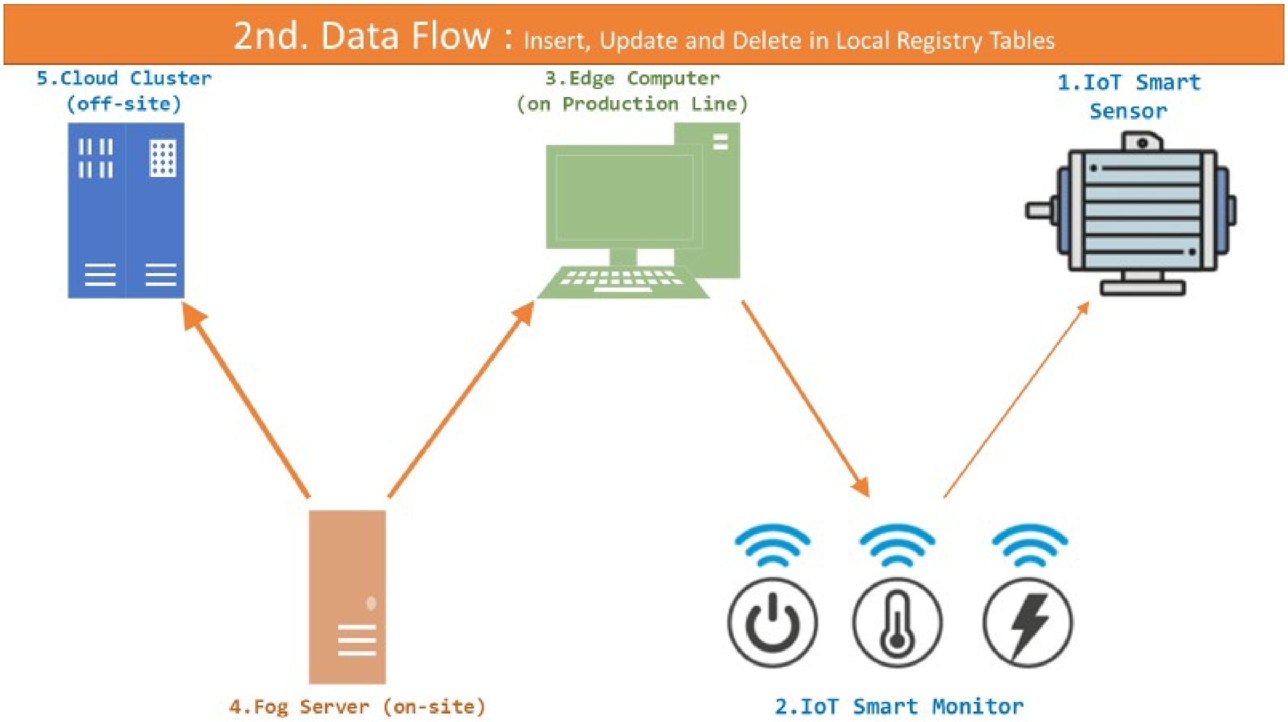
Figure 12 1st Data Flow (my system architecture)



This is the main data flow because it represents the information flowing from the source (smart sensor) and being processed (edge and fog) along the way to the permanent storage (fog and cloud).

4.2 - Local Registry Data Flow

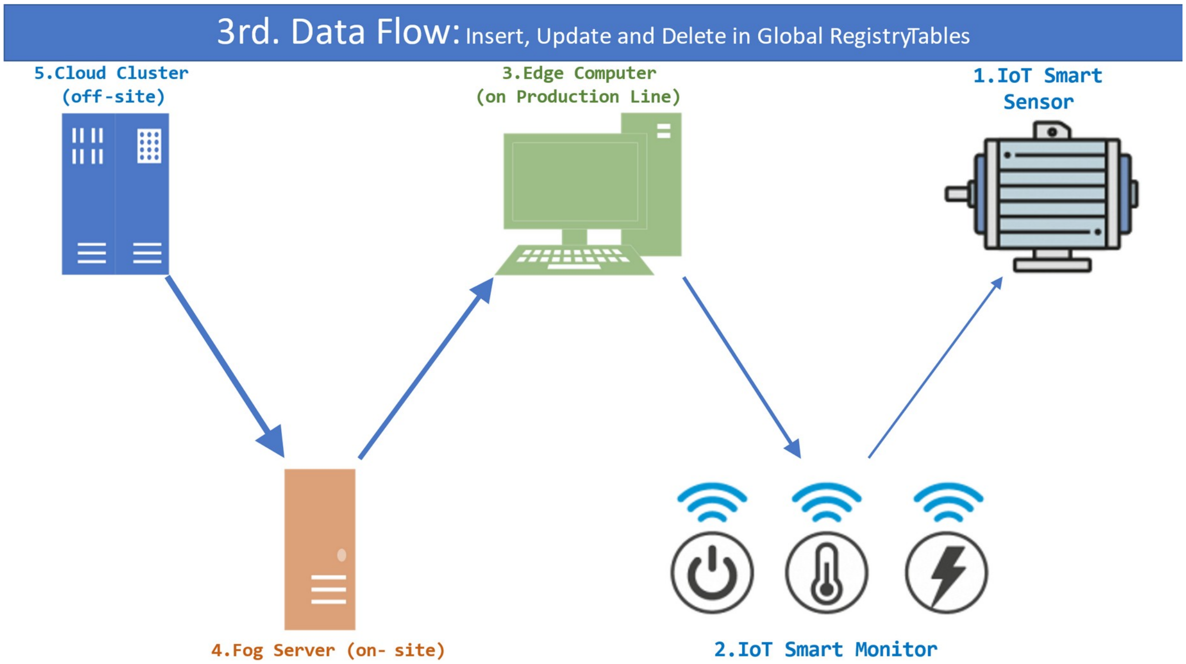
Figure 13 2nd Data Flow (my system architecture)



This is the main Secondary dataflow this represents client specific information flowing from the source to the backup (cloud), big shards(edge) and small shards(monitor).

4.3 - Global Registry Data Flow

Figure 14 3rd Data Flow



4.4 - IoT Smart Sensor ETL

Each one of the 13 smart Sensors is connected to a single sensor attached to a machine. Because of this each one of them performs a different ETL task that. This ETL Tasks transform a sensor output into a rollup and Seven-Number Summary of significative variables. Each smart sensor is limited to a single Feature for analysis. A lot can be done analyzing a unidimensional variable over time. Sum, Count, Min, Max, Median, Mean, First Quartile, Third Quartile, RMS (Root Mean Square), FFT (Fast Furrier Transform) and etc. This means that the smart sensor actually can do almost all the data transformation required to generate: 'Fact data for BI tables' and 'Feature scale for Artificial Intelligence' regression and classification. The aggregation of the sensors ETL is as Follows:

Input (9 types, 13 sensors):

1 1x Thermometer Sensors for Ambient
2 1x Thermometer Sensors for Machine
3 1x Six-Axis Accelerometer and Gyroscope Sensor Combo
4 3x Non-Invasive Electric Current Sensors
5 3x Non-Invasive Electric "Voltage" Sensors
6 1x Incremental Rotary Encoder for Main Electric Motor
7 1x Material Count Sensor
8 1x Product Count Sensor
9 1x Quality Count Sensor

Output (39 Measure Columns):

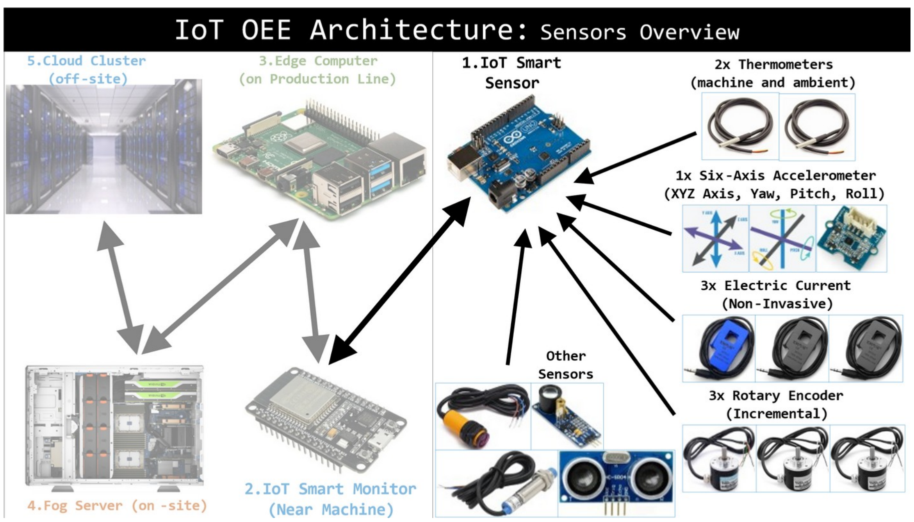
1 **Energy** in Wires 1,2 and 3
  1.1 Frequency (Hz)
  1.2 Current (A)
  1.3 Voltage (V)
  1.4 Power Factor (%)
  1.5 Power (W)

2 **Vibration** All in 6 Axis
  2.1 Acceleration (m/s²)
  2.2 Frequency (Hz)
  2.3 Energy Estimate (J)

3 **Temperature**
  3.1 Machine (K)
  3.2 Ambient (K)
  3.3 Difference (K)

4 **Production** Step Count Sensor
  4.1 Main Electric Motor (un)
  4.2 Product (un)
  4.3 Quality (un)

Figure 15 Sensors Overview (my system architecture)



4.5 - IoT Smart Monitor ETL

Each IoT Smart Monitor is directly attached to a single machine and its sensors. This mean that the monitor has direct access to all the information necessary to generate fact data for BI tables and do Artificial Intelligence regression and classification. Because the previous ETL workload (sensor) already did most of the 'heavy lifting' this means the Monitor is not CPU bound. But only memory bound by its 520KB ram and only in some cases where AI algorithms uses too much memory. The IoT Smart Monitor ETL is as Follows:
(Sistema monitoramento consumo Energia, 2016)

Input (39 Measure Columns):

1 **Energy** in Wires 1,2 and 3
  1.1 Frequency (Hz)
  1.2 Current (A)
  1.3 Voltage (V)
  1.4 Power Factor (%)
  1.5 Power (W)

2 **Vibration** All in 6 Axis
  2.1 Acceleration (m/s²)
  2.2 Frequency (Hz)
  2.3 Energy Estimate (J)

3 **Temperature**
  3.1 Machine (K)
  3.2 Ambient (K)
  3.3 Difference (K)

4. **Production** Step Count Sensor
    4.1 Main Electric Motor (un)
    4.2 Product (un)
    4.3 Quality (un)

Output (49 Indicator Columns):

Indicators (11 Columns)

1. All Time (H)
2. Planned production time (H)
3. Schedule Loss (H)
4. Run Time (H)
5. Availability Loss (H)
6. Net Performance (un)
7. Performance Loss (un)
8. Fully Productive (un)
9. Quality Loss (un)
10. Energy (W)
11. Vibration (J)

KPIs (30 Columns)

1. TEEP (Actual, Green, BP, Red) (%)
2. OEE (Actual, Green, BP, Red) (%)
3. Availability (Actual, Green, BP, Red) (%)
4. Performance (Actual, Green, BP, Red) (%)
5. Quality (Actual, Green, BP, Red) (%)
6. Energy (Actual, Green, BP, Red) (%)
7. Hourly Cost (Actual, Green, BP, Red) (%)
8. MTBF - Mean Time Between Failure (H)
9. MTTR - Mean Time to Recover (H)

Labels added by Operators (10 Columns)

1. Production Order (Start/End)
2. Machine Running (Start/End)
3. Machine Stop (Start/End)
4. Machine OK (Start/End)
5. Machine Break (Start/End)
6. Not in Maintenance (Start/End)
7. In Planned Maintenance (Start/End)
8. In Unplanned Maintenance (Start/End)

Run time hour meters

1. Since Last Breakdown
2. Until Next Breakdown
3. Since Last Panned Maintenance
4. Until Next Panned Maintenance
5. Since Last Unpanned Maintenance
6. Until Next Unpanned Maintenance

4.5 - Edge Computer ETL

The Edge Computer ETL is as Follows:

Input (49 Indicator Columns):

Indicators (11 Columns)

1. All Time (H)
2. Planned production time (H)
3. Schedule Loss (H)
4. Run Time (H)
5. Availability Loss (H)
6. Net Performance (un)
7. Performance Loss (un)
8. Fully Productive (un)
9. Quality Loss (un)
10. Energy (W)
11. Vibration (J)

KPIs (30 Columns)

1. TEEP (Actual, Green, BP, Red) (%)
2. OEE (Actual, Green, BP, Red) (%)
3. Availability (Actual, Green, BP, Red) (%)
4. Performance (Actual, Green, BP, Red) (%)
5. Quality (Actual, Green, BP, Red) (%)

6 Energy (Actual, Green, BP, Red) (%)
7 Hourly Cost (Actual, Green, BP, Red) (%)
8 MTBF - Mean Time Between Failure (H)
9 MTTR - Mean Time to Recover (H)

Labels added by Operators (10 Columns)

1 Production Order (Start/End)
2 Machine Running (Start/End)
3 Machine Stop (Start/End)
4 Machine OK (Start/End)
5 Machine Break (Start/End)
6 Not in Maintenance (Start/End)
7 In Planned Maintenance (Start/End)
8 In Unplanned Maintenance (Start/End)

Run time hour meters

1 Since Last Breakdown
2 Until Next Breakdown
3 Since Last Panned Maintenance
4 Until Next Panned Maintenance
5 Since Last Unpanned Maintenance
6 Until Next Unpanned Maintenance

Output (660 Columns):

Tables:

1 BI Second RollUp
2 BI Minute RollUp
3 BI Hour RollUp
4 BI Shift RollUp
5 BI Day RollUp
6 BI Week RollUp
7 BI Month RollUp

Features summary Columns:

1 Average
2 Sum
3 Count
4 Standard Deviation
5 Minimum
6 2nd percentile (best 2.1%)
7 9th percentile (best 8.8%)
8 25th percentile (1stquartile)
9 50th percentile (median)
10 75th percentile (3rd quartile)
11 91st percentile (best 91%)
12 98th percentile (best 97%)
13 Maximum

5 - Distributed System Fault Tolerance

Because the number of components in the system is high and they are connected in a hierarchical topology the system uptime goes down drastically in comparison to the components up time. This happens because the system has only one network route. The expected uptime is exemplified in the table below as product of the uptime of its components.

Table 4 System Expected Uptime

Quality	1-Cloud Cluster	2 - Fog Server	3 - Edge Computer	4 - IoT Monitor	5 - Monitored Thing	Expected Uptime in Network V1
Excellent	99,95%	99,90%	99,80%	99,60%	99,95%	**99,20%**
Very Good	99,75%	99,50%	99,00%	98,02%	99,75%	**96,07%**
Good	99,25%	**98,51%**	**97,04%**	**94,17%**	99,50%	**88,90%**
OK	**97,77%**	**95,59%**	**91,38%**	**83,51%**	**99,00%**	**70,61%**
Bad	**93,46%**	87,36%	76,31%	66,66%	**98,02%**	**40,71%**
Very Bad	87,36%	76,31%	58,24%	52,27%	96,07%	**19,49%**
Awfull	76,31%	58,24%	33,91%	11,50%	94,17%	**01,63%**

The following images show all the possible problems the distributed system can have and the more immediate solution for those problems

Figure 16 Problem Group 1 (my system architecture)

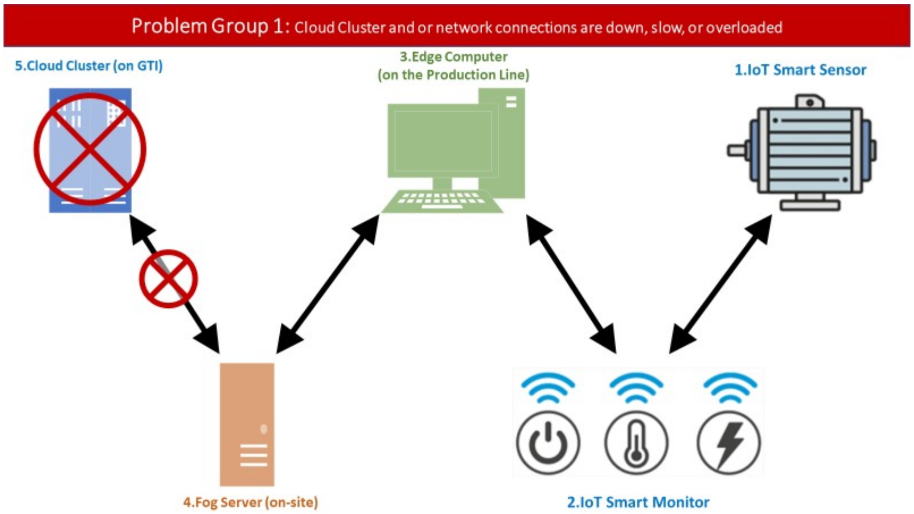


Figure 17 Problem Group 2 (my system architecture)

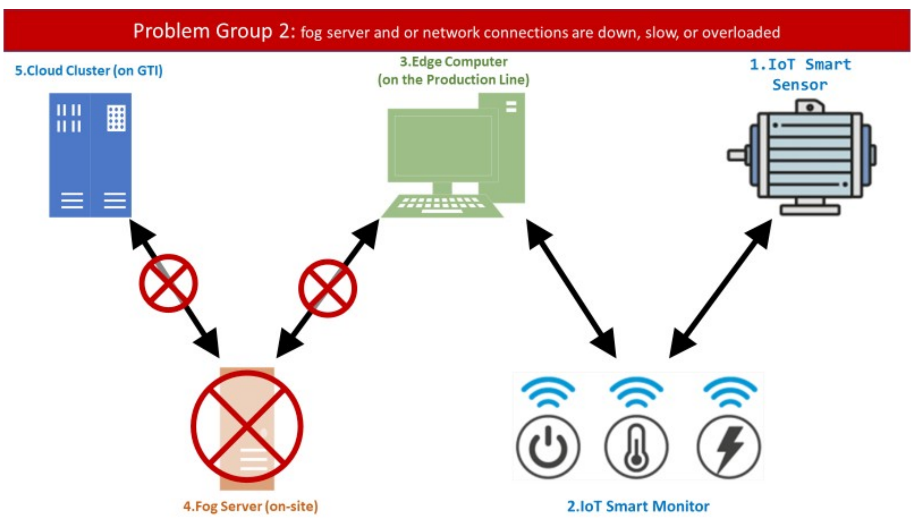


Figure 18 Solutions Group 1&2 (my system architecture)

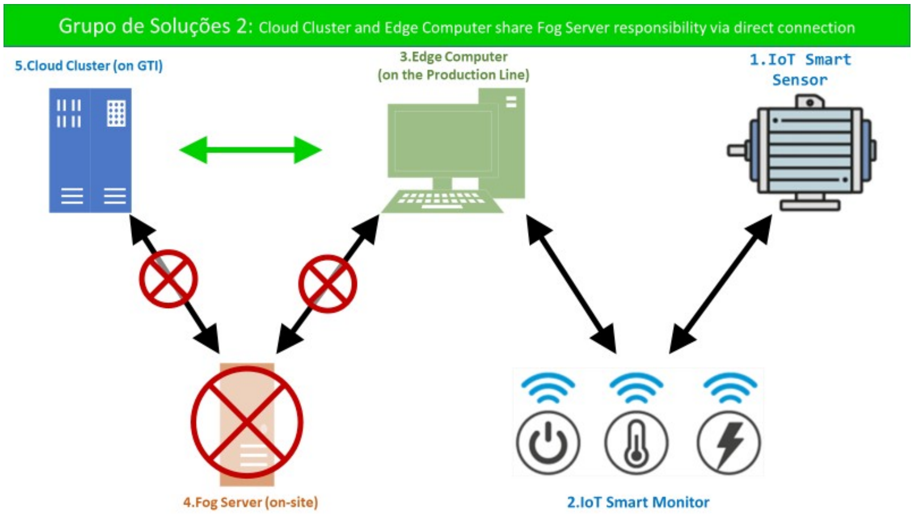


Figure 19 Problem Group 3 (my system architecture)

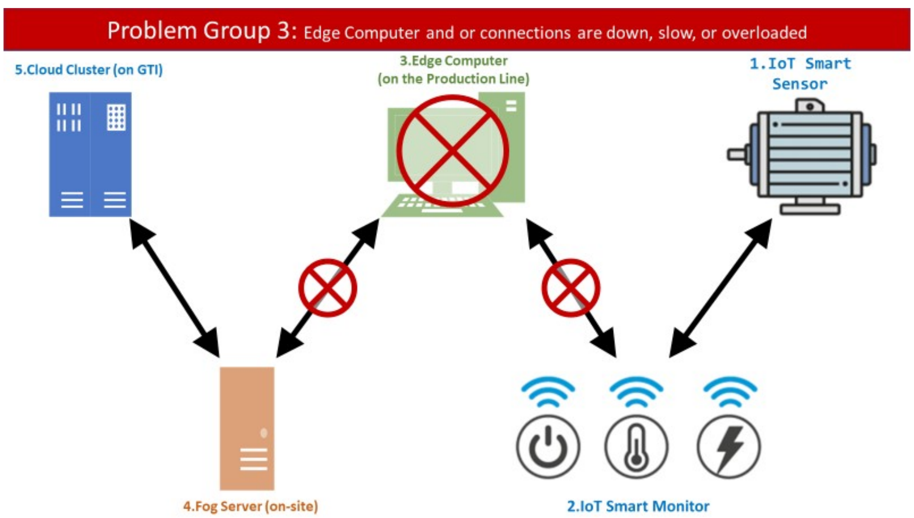


Figure 20 Solution Group 3 (my system architecture)

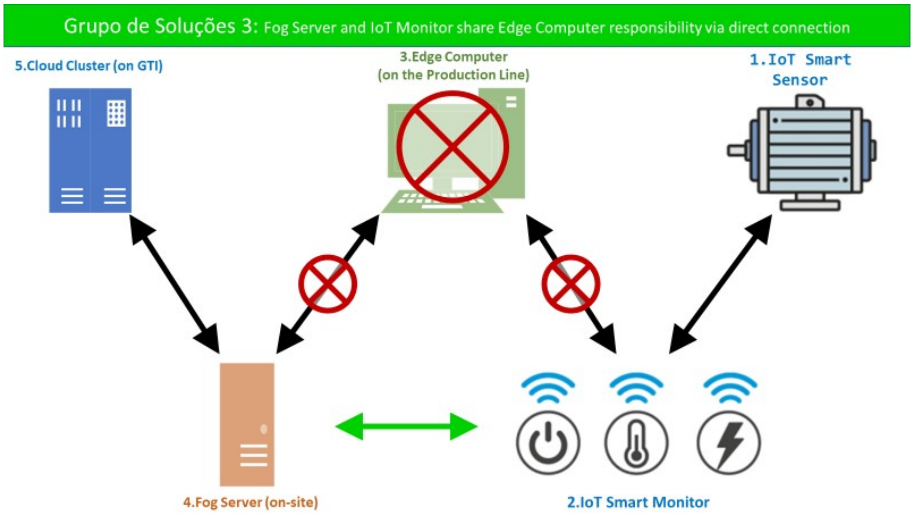


Figure 21 Problem Group 4 (my system architecture)

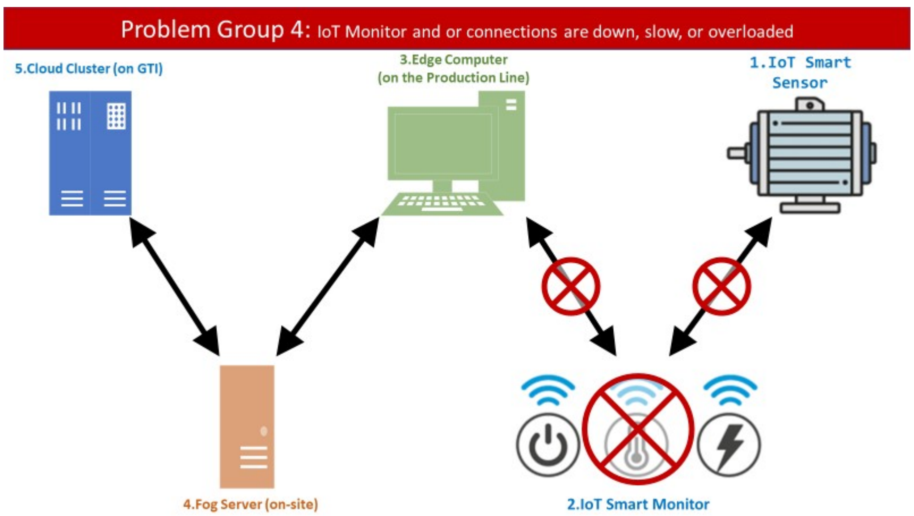


Figure 22 Solution Group 4 (my system architecture)

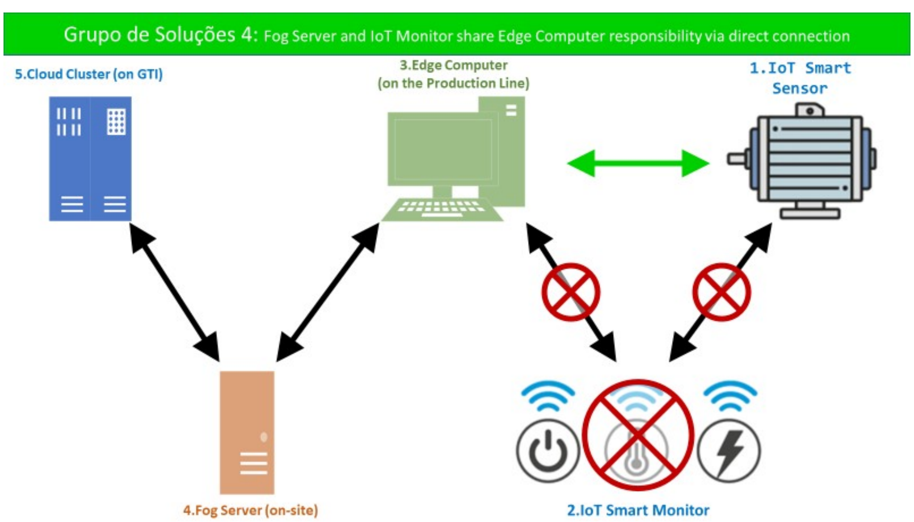


Figure 23 Network Architecture V2

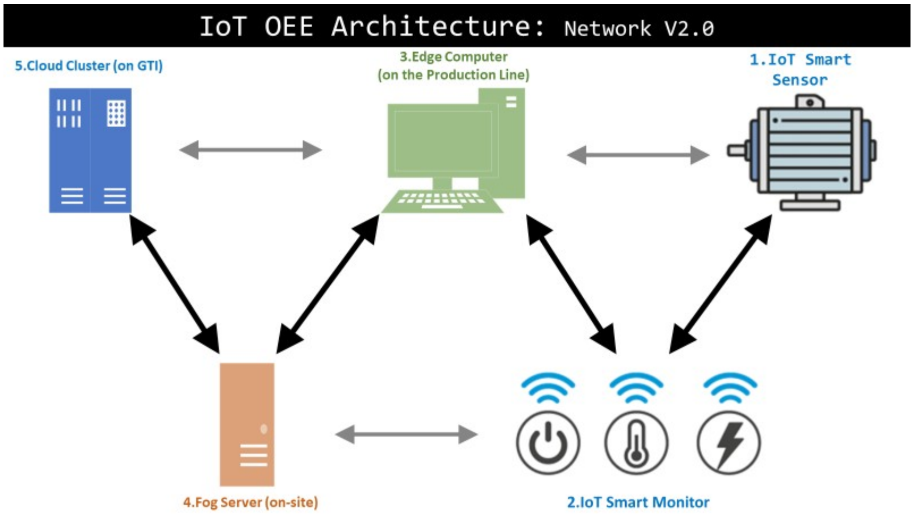


Figure 24 Network Architecture V3

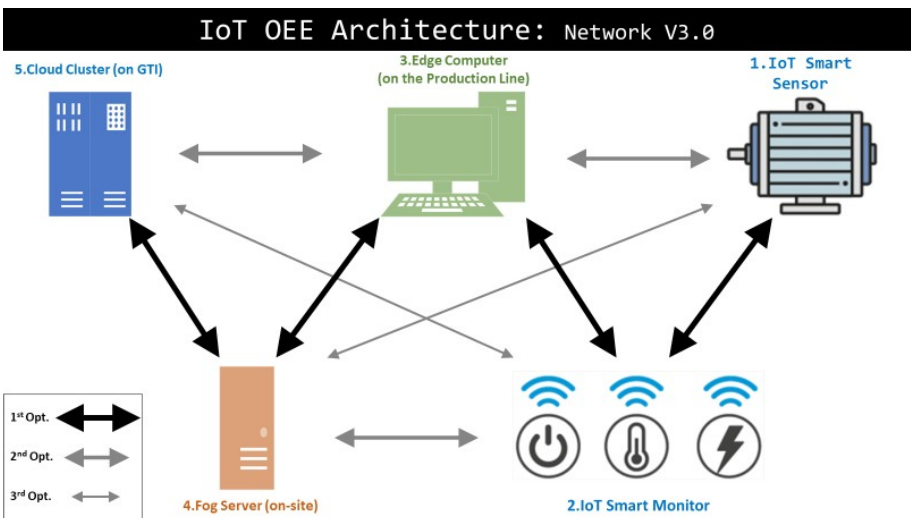


Figure 25 Network Architecture V4

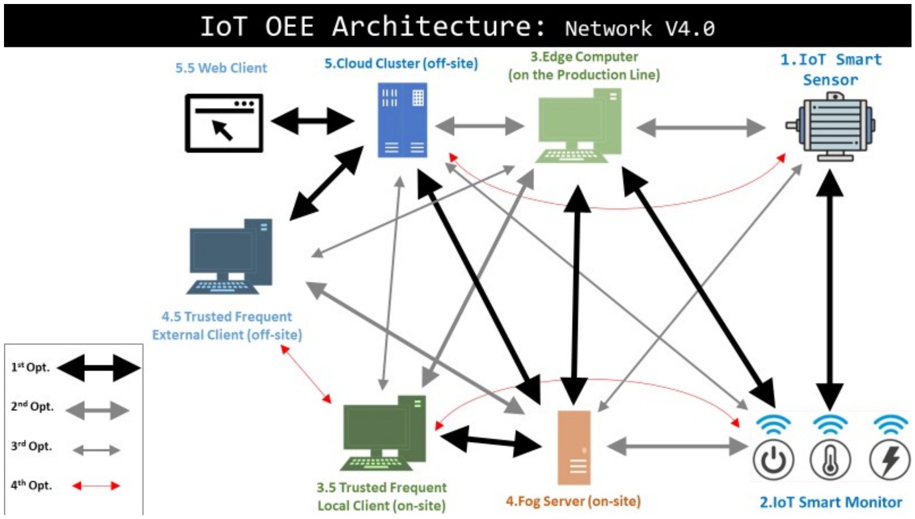


Table 5 Network Architecture Uptime Comparison

Quality	1-Cloud Cluster	2 - Fog Server	3 - Edge Computer	4 - IoT Monitor	5 - Monitored Thing	Expected Uptime in Network V1	Expected Uptime in Network V3
Excellent	99,95%	99,90%	99,80%	99,60%	99,95%	**99,20%**	99,40%
Very Good	99,75%	99,50%	99,00%	98,02%	99,75%	**96,07%**	97,04%
Good	99,25%	**98,51%**	**97,04%**	**94,17%**	99,50%	**88,90%**	91,38%
OK	**97,77%**	**95,59%**	**91,38%**	**83,51%**	**99,00%**	**70,61%**	76,31%
Bad	**93,46%**	87,36%	76,31%	66,66%	**98,02%**	**40,71%**	50,87%
Very Bad	87,36%	76,31%	58,24%	52,27%	96,07%	**19,49%**	30,44%
Awfull	76,31%	58,24%	33,91%	11,50%	94,17%	**01,63%**	03,90%

Table five demonstrates that the System Uptime dramatically increase from architecture 1 trout 4. The difference between systems is displayed on figure 23 trout 25.

6 - Distributed System Architecture and Processes

6.1 - Distributed Tables (to divide database by client and machine)

These tables seem normal to SQL queries, however they are horizontally partitioned between worker nodes. Here, the rows of the table are kept in the worker-side tables table 1001, table 1002, etc. The individual worker tables are known as shards. Citus executes both SQL and DDL commands across a cluster, thus modifying the schema of a distributed table updates all of its shards across workers. Each formed shard receives a unique shard identifier. Each shard is represented on the worker node as a standard PostgreSQL table with the name 'tablename shardid', where tablename is the name of the distributed table and shardid is the unique identifier for that shard. To see or execute commands on specific shards, you may connect to the worker Postgres instances.

Figure 26 Distributed Table Benefits

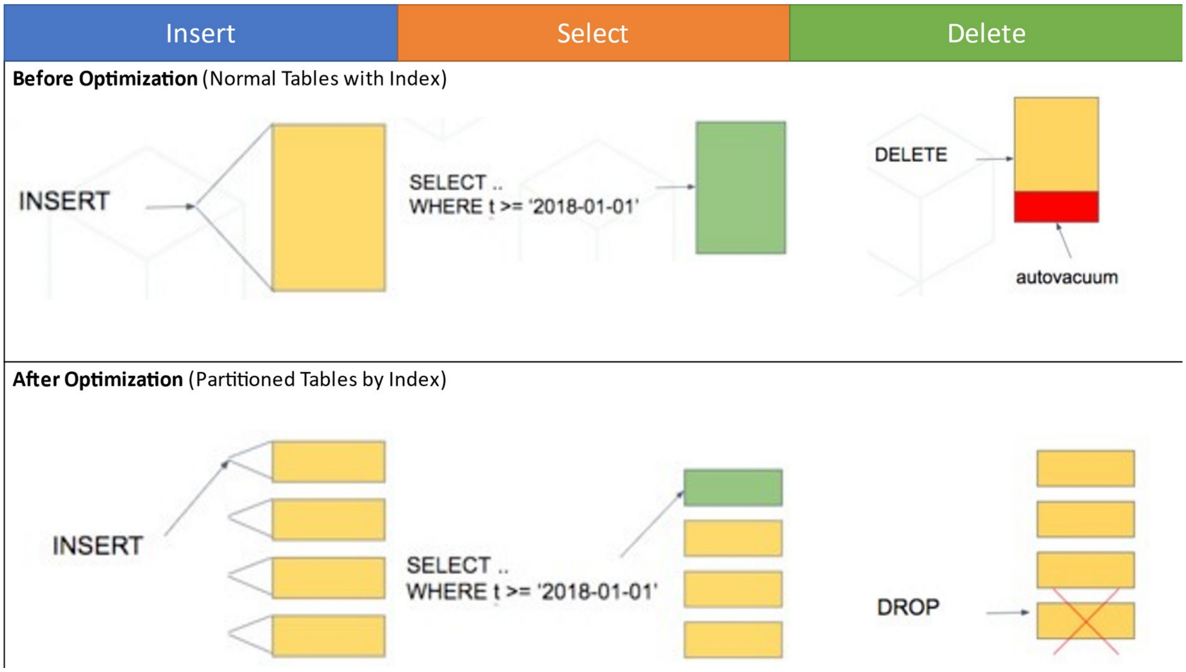
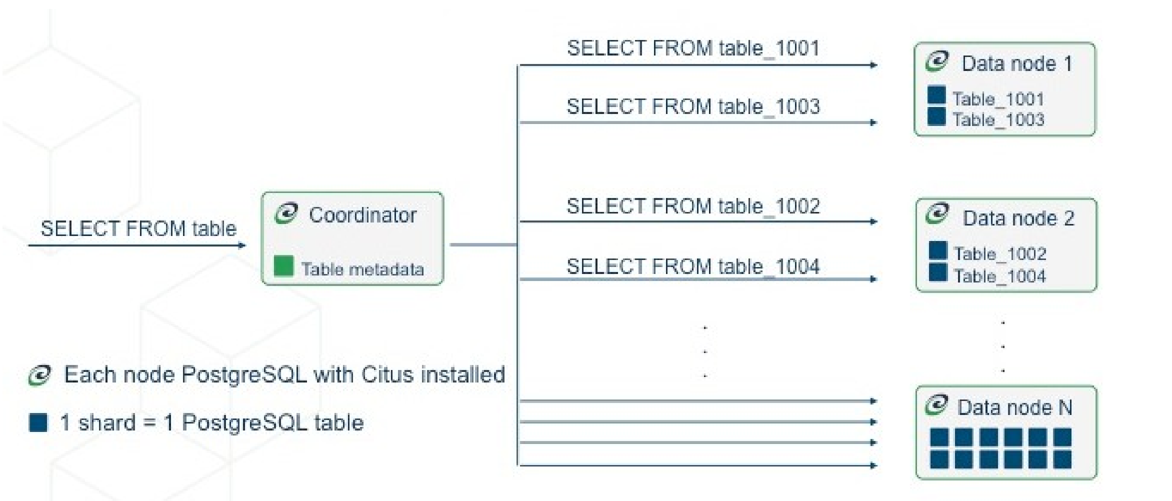


Figure 27 Distributed Table Example



6.2 - Reference Tables

The contents of a distributed reference table are condensed into a single shard that is replicated on each worker. Therefore, queries on any worker may access the reference data locally without incurring the network expense of requesting rows from another node. There is no requirement to separate unique shards each row; hence, reference tables do not need distribution columns. Reference tables are used to store data pertinent to queries executed on any worker node. Examples of enumerated information are order statuses and product categories. Transactions using a reference table are automatically committed in two parts. This indicates that Citus protects the consistency of your data regardless of whether it is being generated, edited, or removed.

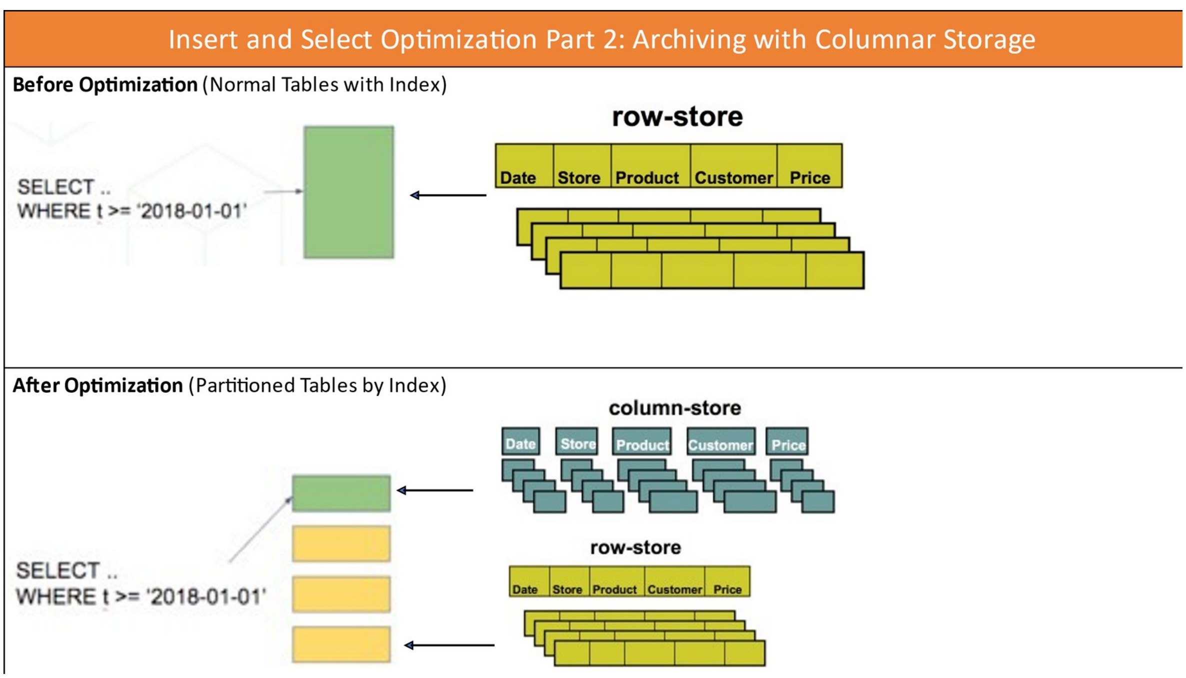
Examples of typical reference table candidates (In our application this tables are the standard machine types, standard work shift, standard KPI type, Country, State, City etc.):

- Connecting smaller dispersed tables to larger distributed tables.
- Tables in multi-tenant systems that lack a tenant id column or tenant association. (In rare circumstances, to reduce migration effort, users may elect to generate reference tables from tenant-related tables without a tenant id.)
- Small tables that need separate limitations across several columns.

6.3 - Columnar Storage (for fast timeseries archive retrieval)

Citus 10 introduces append-only columnar table storage for analytic and data warehousing workloads. When columns (rather than rows) are stored contiguously on disk, data becomes more compressible, and queries can request a subset of columns more quickly. (https://docs.citusdata.com/en/v11.1/get_started/concepts.html#type-1-distributed-tables, 2022)

Figure 28 Fast Read, Slow Wright, Table (from citusdata)



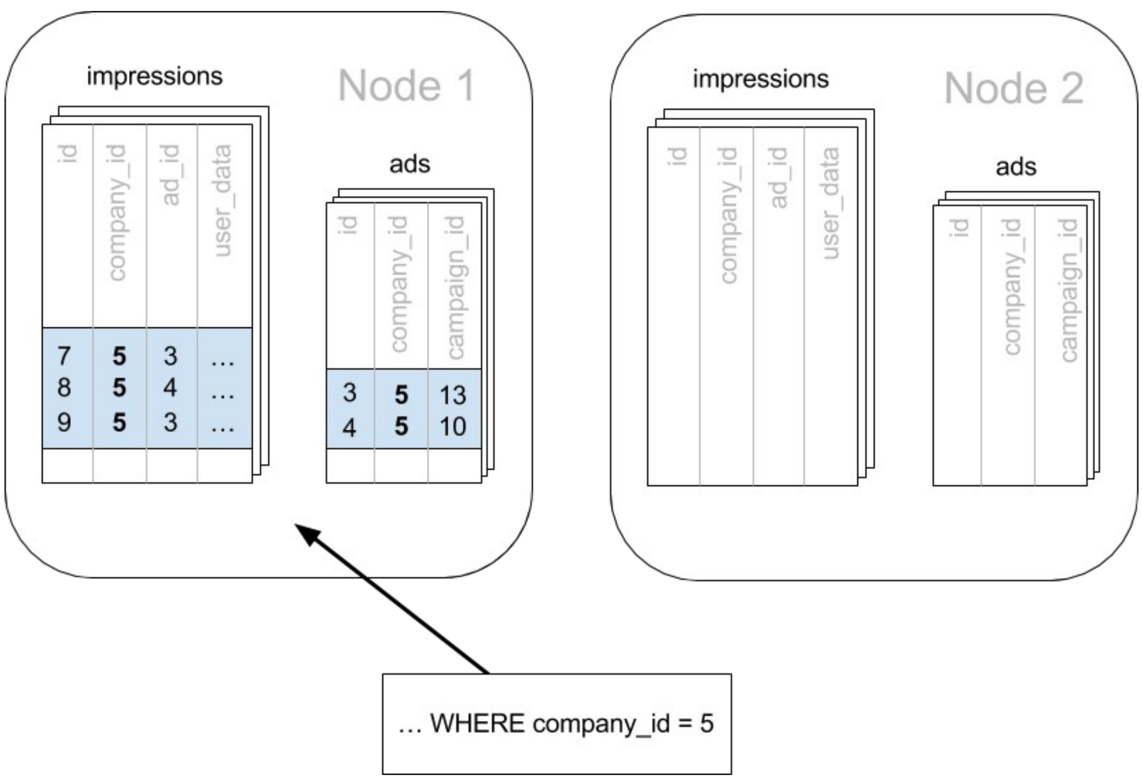
6.4 - Multitenancy

Software multitenancy is a software architecture in which a single instance of software runs on a server cluster and serves multiple tenants. These are "shared" systems (rather than "dedicated" or "isolated"). A tenant is a collection of users with shared software privileges. Multitenant architecture gives each tenant a dedicated share of the instance's data, configuration, user administration, functionality, and non-functional features. Multitenancy contrasts with multi-instance systems, where distinct tenants use independent software instances.

If you're designing a SaaS app, tenancy is definitely already in your data model. The database tables capture this natural tenant/customer/account relation. SaaS applications can store each tenant's data in a separate database instance, hidden from other renters. This is three-fold efficient. First, app updates benefit all clients. Second, database sharing saves hardware. Last, a single database for all tenants is easier to operate than separate database servers.

A single relational database instance has problems scaling to a large multi-tenant application's data volume. When data exceeded a single database node's capacity, developers abandoned the relational approach. Citus lets customers develop multi-tenant applications as though they're connected to a single PostgreSQL database, while the database is a cluster of servers. Client code needs minimal changes to continue using SQL.

Figure 29 Multi-tenancy Table Example (from citusdata)



Multi-tenancy. Sharing a single, pooled, operational instance of the full top-to-bottom infrastructure is necessary for cloud scaling. Consider the surrounding as-a-service infrastructure and any cloud-connecting frameworks. Understand the value of regularly tuning and refreshing infrastructure to keep up with hundreds or thousands of tenants. Conservatives continually look for dangers and weaknesses. Progressives will want new features implemented quickly. Every tenant benefits from sharing the outcomes of these two extremes and all points in between, battle-hardening and future-proofing the common infrastructure. Every change and improvement is immediately available to all tenants.

Tables and data. In the previous part, we found the correct distribution column: company id. Even in a single-machine database, adding company id can denormalize tables for row-level security or indexing. Including the extra column also helps with multi-machine scaling. Each table's main key in our schema is an id column. Citus requires distribution column in primary and foreign key constraints. This requirement makes enforcing restrictions in a distributed context more efficient, as only a single node must be examined. This means including company id in SQL main and foreign keys. This works for multi-tenant since we need per-tenant uniqueness. These updates prepare the tables for company id distribution. The create distributed table function tells Citus to distribute a table among nodes and distribute incoming queries. The function builds table shards on worker nodes, which Citus uses to assign data to nodes.

6.5 - Shard Placements

Since shards may be placed on nodes based on choice, it makes sense to place shards containing relevant entries from related tables on the same nodes. Thus, join queries may be conducted inside a single Citus node without the need to transport as much data across the network. An example would be a database that includes all the information only one company being stored on each Fog Server. Another example would be an Edge Computer storing information of up to 15 machines under its Shard of the database. If all tables have a tenant_id and machine_id field and are distributed by it, all queries confined to a single tenant_id or machine_id may execute effectively on a single worker node. Regardless of the table combinations included in the queries, this holds true. (https://docs.citusdata.com/en/v11.1/get_started/concepts.html#shard-placements, 2022)

7 - Conclusion

Creating a IoT System to measure OEE is possible and commercially viable. The combination of a multitenant distributed system with and optimized database for large time series data ingestion, and with edge computing and fog computing is able to execute Artificial Intelligence Regression and Classification cost effectively. The network and ETL topology are very important for the System uptime. MTBR, MTTR, OEE and its components are very effective Indicators capable of increasing industrial productivity substantially in most cases. IoT is Very useful for the industry 4.0.

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