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A Case-study Vision

Characterization of automated systems integrated to a BMS: Successful case El Dorado International Airport

Caracterización de sistemas automatizados integrados a un BMS: Caso exitoso Aeropuerto Internacional El Dorado

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ABSTRACT:

The article describes and characterizes the systems integrated into the Building Management System -BMS- of El Dorado International Airport: air conditioning, electrical system, fire detection, dry extinction, vertical and horizontal transport, plumbing, handling of luggage and access control system, from an exploratory investigation. To this end, a conceptual review is carried out on the subject and a methodology is proposed where the sources are sectioned based on a categorical taxonomy. The search for information focused on the databases: IEEE Xplore, Google Scholar, and expert knowledge validated by the ORCA research group. A characterization of the automation systems that are integrated in the BMS of the airport is obtained where, analyzing the integrations, it is recurrent that manufacturers or brands work with more open protocols for integration, and not have to resort to other means integrators such as the Field Server that was used in several of the systems identified at review

RESUMEN

En el artículo se realiza una descripción y caracterización de los sistemas integrados al Building Management System -BMS- del Aeropuerto Internacional El Dorado: aire acondicionado, sistema eléctrico, detección de incendios, extinción seca, transporte vertical y horizontal, plomería, manejo de equipaje y sistema de control de acceso, a partir de una investigación de carácter exploratorio. Para tal fin, se realiza una revisión conceptual sobre el tema y se plantea una metodología donde las fuentes se seleccionan en base a una taxonomía de tipo categórico. La búsqueda de información se centró en las bases de datos: IEEE xplore, Google Scholar, y el conocimiento de expertos validado por el grupo de investigación ORCA. Se obtiene una caracterización de los sistemas de automatización que se encuentran integrados en el BMS del aeropuerto donde, analizando las integraciones, es recurrente que fabricantes o marcas trabajen con protocolos más abiertos para la integración, y de este modo no recurrir a otros medios como el Field Server utilizado en varios de los sistemas identificados en la revisión.

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1. Introduction

El Dorado International Airport in Bogotá (Colombia), which will be 60 years old, began its modernization and expansion process in September 2007. With the law 1529 of May 16, 2012 it assumed the name of: El Dorado Luis Carlos Galán Sarmiento International Airport, [1]. It currently has three terminals, two for passenger transport and one for cargo transport, which are an added value in airport modernization, [2].
As a consequence of the policy described above, it has been ranked among the best airports in Latin America: in 2018 -and for third consecutive year- Skytrax, (British firm specialized in international air transport quality) [3] awarded El Dorado with the recognition as the best airport in South America -within the World Airport Awards framework- international air transport rating organization, Skytrax [4] Research from London, United Kingdom, dedicated to analysis and quality comparison of different airlines and airports in 14 regions of the world. Here, the applied criteria are shown, Table 1.

Quality	Processes	Services	Excellence
Quality standards in air transport industry. Design and infrastructure indicators.	Flow indicators in airportprocesses. Standardized operating systems with high tech controls. Efficiency indicators in relation to employed resources.	User care indicators: attitude, information, versatility in communication in different languages.	Skytrax Standards - World Airport Awards- a quality award given to worldwide airports.

Table 1. Criteria taken into account in airport evaluation by Skytrax. Source: own.

By May 2019, the airport will receive Level *2 Reduction Certification from Airport Carbon Accreditation*, by the Airports Council International for Latin America and the Caribbean (ACI-LAC), due to energy savings from improvements in air conditioning, ventilation and lighting systems.
According to Huang et al., "airports are more than just an installation, they are a multifunctional space for social interactions and individual experiences that break down geographical boundaries", [5]. And in that sense, by 2019, the first place in Latin America would be occupied by Lima's airport, followed by Quito's, and Bogotá's would be in third place - and in 53rd place worldwide [6]. Thus, El Dorado became a four-star airport in South America [7], surpassing airports such as New York, Madrid or Paris, which do not exceed three stars.
In addition, research shows that El Dorado is ranked fifth in the world among airports with more than 30 million passengers per year, and is the only airport in Latin America to figure in this ranking, [8].

Acronyms, abbreviation	
BMS	building management system
FADS	fire alarm and detection system
BHS	baggage handling and storage
METASYS	automation and management platform
ADX	administration software
NAE	network controller
NCE	network and field controller
FEC	field controller
IOM	expansion module
LAN	local area network
IT	information technology
TVH	vertical and horizontal transport
HVAC	Heating, ventilation and air conditioning system
SE	Electrical system
SACS	location and security system

Table 2. Acronyms, abbreviations. Source: own.

In accordance with the above, regarding the management and improvement of processes, the airport has been catalogued as an executor of good practices; however, at technological level, there is still a demand for optimization of these processes, see Table 2, as a favorable mechanism for standardization and competitiveness of it.

2. BMS basic structure

In terminal one there are different electronic systems that are part of its infrastructure: 1. Vertical and that are part of its infrastructure: **1. Vertical and horizontal transport -TVH-:** made up of elevators, stairs and rolling mats; **2. BHS**[3]**:** made up of conveyor belts for baggage handling; **3. HVAC**[4]**:** refers to air conditioning system in air terminal; **4. Electrical system –SE-:** according to lighting system, electrical substations; **5. Plumbing:** relates to terminal water system maintenance; **6. SACS**[5]**:** used for authentication, identification, observation and monitoring of entry into restricted areas; **7. Dry extinction -BD y FD** : firefighting system used in Data Centers; **8. Fire detection system FADS**[6]**:** concerning the fire alarm system. All of the above are integrated into the building management system (**BMS**[7]), [9].

On the other hand, the BMS system installed in terminal one, Figure 1 - has as its main objective to increase energy efficiency, increase security levels, passenger comfort, provide a comfortable, convenient and safe environment; reducing the terminal's operating costs; for this reason, it has automated equipment whose functions allow adjusting monitored variables in integrated systems to maintain its optimal operation. To this end, the system has an open and Ethernet type installed architecture, using **BACNET IP**[8] communication protocols, [10]. And in its architecture it has two redundant servers that manage the external database through a server that handles network controllers which in turn integrate field controllers connected to sensors and actuators for each system. *BMS* manages different systems with the possibility of integration through Control and/or Supervision actions, as indicated in Table 3.

SYSTEM SPECS		
ITEM	SYSTEM	ACTION
1	HVAC	Monitoring and Control
2	ELECTRICAL-SUBSTATIONS AND POWER PLANTS	Monitoring
3	FADS	Monitoring
4	LIGHTING	Monitoring and Control
5	PLUMBING	Monitoring
6	TVH	Monitoring
7	BHS	Monitoring
8	DRY EXTINCTION	Monitoring
9	SACS	Monitoring
10	ELECTRICAL- UPS	Monitoring

Table 3. Integration of BMS into systems. Source: own.

Figure 1. BMS building management system El Dorado International Airport. [12]

3 Automated system used for handling and verification of luggage that is monitored and controlled from the time it enters the counter until it is removed by security personnel, to be mounted on the aircraft.
4 Heating, ventilation and air conditioning system
5 Location and security system
6 Building Distributor and Floor Distributor
7 Building management system based on monitoring and control software and hardware, is a full automation system with high technology.
8 Data communication protocol designed to communicate between different electronic devices present in today's buildings (alarms, passage sensors, air conditioning, heaters, etc.)

With technological innovations introduced in air terminals, it has been sought to be at the forefront of service in line with globalization - a worldwide economic, technological, political, social and cultural process - and what it means to host or receive citizens from all over the world, [11].

This paper wants to present integrated systems to a BMS Figure 2- at one of the best airports in South America, taking into account that little information is found on this subject -in academic literature- about characterization of BMS systems at airports.

Figure 2. BMS system El Dorado International Airport. Source: own.

To do so, it is organized as follows: an introduction presents the importance of El Dorado Airport worldwide and its relevance in Latin America [13], focusing on the study of technological development involving automated systems integrated into a BMS; then, a brief description of how the system is made up is given in the basic structure, and methodology describes the objective of analyzing the system's architecture and how it is interpreted. Afterwards, a detailed description is made where each of the systems integrated to BMS is characterized by analyzing all the gathered information and technical characteristics of the system. Finally, conclusions are drawn and ideas obtained in the research are argued in order to have a sequential baseline in the characterization of automated systems for future research on logistics, monitoring of quantitative and qualitative variables, and in general for the implementation of versatile technological solutions related to instrumentation and control.

3. Methodology

The present exploratory documentary research categorized and subcategorized the BMS - Figure 3 - with the objective of having a baseline to characterize technological and automation systems integrated in air terminals, focusing on achieving a network architecture managed in integration of different systems in an airport that behaves reliably and guarantees the safety of and in the facilities. For this purpose, the methodology used was based on an index definition proposed in [14].

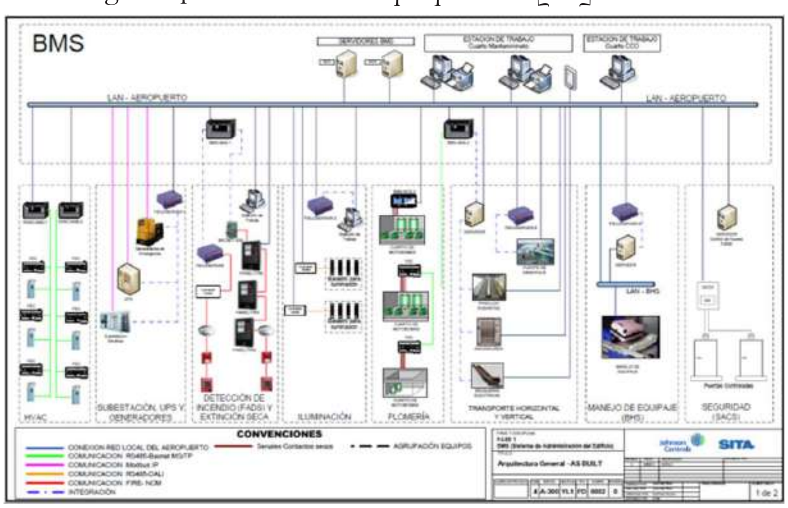

Figure 3. BMS system El Dorado International Airport. [15]

According to that definition, the key search words that will be followed to determine the data sources are Automation, BMS systems, airport integration. In this sense, study sources are defined in: web sites about BMS systems characterization; papers by Google Scholar, IEEE among others and expert knowledge validated by the ORCA research group.
Then, a description of the sources and their interpretation is followed, seeking to characterize identified technological systems. Finally, a comparison is made with the implemented systems in El Dorado.

4. BMS characterization (source description and interpretation)

Application of new technologies is becoming more and more important to society, this is why El Dorado implemented technological innovations from 2012, including a BMS integrating the systems shown in Figure 2 above, which are described below.

4.1. Metasys, [16]: is a building management system that integrates multiple sensors and controllers. It centralizes, controls and monitors the systems installed in the air terminal so that they work together; this automation and management platform uses popular communications protocols to integrate with other systems in the terminal. Advanced reporting allows data collection, summarization and presentation of integrated systems in a relevant and useful way; works based on the latest web and wireless technologies, programming runs on Java[9] [17], with a IT[10] software based system [18], and Bacnet protocol, [19].
In summary, different field controllers are configured there: FEC, IOM, NCE[11], and in its structure - which is its software program - it has SCT[12], with a network controller that integrates the other controllers and synchronizes with ADS[13].

4.2. BMS ADX[14]: is an extended application server (ADX) [20], which provides storage and management of historical data, graphs, reports, trends, schedules - among others-; it has the capacity to support up to 10 users connected to Internet through their web browser and allows you to report, configure, and schedule historical data files through standard storage such as Microsoft SQL Server[15] and Windows server[16] version 8.0- using a user interface that goes from a general level to a detailed level of equipments in a certain area or category having pop-ups in different alarms that are generated in the system

4.3. Air conditioning

HVAC: (Heating, ventilation and air conditioning system), [21]. The system regulates speed, temperature and amount of air entering, with this system is provided in El Dorado Airport Terminal 1 an environment where temperature, humidity and air purification are comfortable, is distributed along the air terminal - Figure 4 - in areas such as: waiting rooms, public areas, food courts, data center among others. This ventilation and air conditioning system operates through the statistical and mathematical software called Montecarlo,[17] [22].

To guarantee this, the system has a main cold-water plant with 3 centrifugal chillers,[18] [23] that manage airport comfort and 7 air-condensed chillers[19] [24] that supply cold water to Datacenter[20] and offices; these cycle in 18 hours periods -approximately- by programming. It has 3 cooling towers that rotate together with the centrifugal chillers, 5 cold water pumps (BAF) of 150Hp each, being 3 of them working with the chillers and 2 of them as a backup, in charge of supplying cold water through the terminal by means of ducts, handling regulation and control valves. The system has 27 package type units (system based on a cooling circuit) 67 air handlers (UMA), 9 supply units ,12 extraction units, 46 ventilation units,46 ET extraction units, 37 cassette type ventilation units, 22 fan coils, 4 XDP and 43 ACP precision units, 11 VED units, mini Split, temperature sensors, CO2, air flow and status sensors, thermocouples and flow rate valves.

9 Object-oriented programming language
10 Study, design, development, innovation implementation, support or management of computerized information systems
11 Network controller engine
12 Provides access to UI including object database configuration, logical user programming and graphical design.
13 Extended Data Server
14 Extended Application Server
15 Database management system
16 Allows the computer to handle network functions such as print server, domain controller, web server and file server.
17 It takes the name of the non-deterministic - or numerical statistical - method used to approximate complex and expensive mathematical expressions to evaluate accurately.
18 Liquid cooling unit that works with water and performs the cooling process through heat exchange.
19 Cooling unit that for this case works by air
20 Data Processing Center

Figure 4. Integrated Air Conditioning Systems El Dorado International Airport. [22]

Regarding the architecture, it has a serial MS/TP [21] Bacnet data bus that runs through all the system's equipment such as FEC [22] and IOM [23], reaching the network controller (NAE[24]) which provides information to the control system (ADX), where it can manage: schedules, trends, and monitor all variables.
These systems, like others that are integrated, are controlled and supervised from BMS where they are monitored 24 hours a day, 365 days a year by specialized technical personnel who handle Metasys® Johnson Controls software, [25].

4.4. Electrical

In the **substations** and plants architecture installed in terminal [26], the integration has a Modbus TCP/IP[25] communication [27] which is connected to the *Airport network;* it is in charge of collecting data from multifunctional meters in electrical distribution boards and emergency generating plants.
It uses a Fieldserver[26] device [28] that reads the Modbus IP[27] data to be converted to Bacnet IP protocol, these are then delivered by it to BMS network controller (NAE) to be read and provide the data to the centralized control system (ADX).

The terminal has four electrical substations, a 34.5 kV main substation and a 11.4 Kv generation center [29], the SIEMENS® Substation Automation System (SAS) [30]; it is based on the SICAM PAS system (Energy Automation System) [31], a SIPROTEC system (integration of protection, control, measurement and automation functions in a single device), and local control panels and actuators, [32].
UPS (Uninterruptible power supply), refers to a source of electrical supply that has batteries in order to continue providing energy to a device in the event of an electrical interruption [33], its architecture is made up of the Modbus TCP/IP communication network which collects data from it and through the Field Server device interprets it to the Bacnet IP protocol, being read by the NAE which supplies data to the ADX system and displayed in SCADA.
Its main function is to analyze trends in energy saving behavior at the airport [34]; therefore, it is of great relevance to increase energy efficiency on a large scale. New advanced power analysis platforms and new control algorithms for managing electricity consumption are also being developed there, [35].
The airport's **lighting** system has an OPC (OLE for Process Control)[28] interface and, like UPS, converts it into an IP Bacnet to be read by the NAE and then taken to the ADX to be visualized in BMS from Metasys –Figure 5-.
For its operation it has a system called ELVIS[29] that allows to make control, monitoring and visualization on terminal illumination by means of software and hardware. It uses KNX network communications protocol for intelligent buildings, [36]. With this system, it is possible to enter remotely or manually and perform tasks such as: identification of anomalies in the system, programming for dimming of the lighting, and schedules for turning the lights on and off in this way, generating savings at the energy level.
On the other hand, in reports the system identifies ballasts and pipes in failure, alerts and history. It has an energy control system DALI[30] (Digital Administrative Lighting interface) which verifies light levels in each space; this way it allows switching off in a sectorized and automatic way in terminal 1.

21 It is a unique data link protocol for Bacnet that is used as a MS/TP field bus is master-slave
22 Field equipment controller
23 Input/output Module
24 Automation engine network controller exclusive to Metasys®
25 Protocol that provides reliable transmission of data packets over networks.
26 Interconnected for Bacnet IP-Bacnet Ethernet- Bacnet MS/TP
27 Communication protocol based on client/server architecture
28 Communication standard used in industrial control and supervision, it is used through a client-server architecture.
29 Automation software.
30 Digital addressable lighting interface.

Figure 5. El Dorado Airport Electrical System Terminal 1. [36]

Figure 6. El Dorado Airport Solar Panels, Terminal 1. [12]

Consequently, research shows that renewable energy use has been considered as the engine for future power generation [37]. The **PHOTOVOLTAIC** system -Figure 6-, resembles the largest solar plant installed in airports in South America, and can be considered a mega environmental, technological, economic and aeronautical project. The installation consists of 10,369 panels installed on a 270 Watt roof, with 2 MPPT (Maximum Power Point Tracker) inverters. This system handles a power of 2.8 **MWp,** generating an annual production of 3.9 **GWh**/year[31]; it has an average coverage of 12% of terminal energy consumption, avoiding the emission of 1,375 tons of CO_2, which is equivalent to average oxygen emitted by 76,433 mature trees and generation produced is equivalent to approximately 1,632 homes. These systems are implemented at national and international airports, [38].

4.5. FADS (Fire Alarm Detection System)

The fire protection system operates several devices that warn people, by means of a visual and auditory device, of any new emergency situation that may arise, [39]. This architecture handles an interface through the Bacnet IP protocol; its port integration interface is the Ethernet RJ45 for the FADS communication card, connecting to the airport's local network (LAN) using FIRE-NCM[32] communication, which is subsequently read by the network controller (NAE) and in the same way sending data to the ADX centralized control.

Figure 7. El Dorado Airport Fire Machine and FADS system, Terminal 1. Source: own.

From BMS operations center, all events, news or alarms registered by system are supervised; this information is handled in parallel with Aerocivil's OPAIN[33] aeronautical firefighting group [40] -Figure 7- who are available 24 hours a day, 365 days a year to attend any emergency. Different alarms or events registered by system can be triggered by smoke or heat detectors or manual fire alarms.

4.6. Dry extinction BD and FD

Dry extinguishing system at El Dorado Airport is installed in **BD** and **FD** where several air terminal data centers are located, - Figure 8 - it consists of an active media of protection against fire by means of extinguishing agents contained in bottles and conducted through pipes to devices for its discharge.

Different designs of this system are used for intelligent buildings [41]; in **BMS,** and in parallel with Aeronautical Fire Department of the airport, dry fire extinguishing system is integrated, which uses a Fike Cheetah protocol, which connects to the Field server using RS-485 connection, making it a Bacnet IP to take data to ADX central control and be supervised in SCADA.

31 Gigawatt hour/year
32 Fire alarm communication module network.
33 El Dorado International Airport Consortium.

Figure 8. El Dorado Airport FADS System Datacenter, Terminal 1. Source: own.

4.7. Vertical and horizontal transport (TVH)

The airport has 25 electric staircases, 20 roller mats and 63 elevators. The architecture of this system for elevators, escalators and moving walkways is based on Colombian technical standard NTC 5926-1,[34] [42] using Bacnet IP communication protocol through a communication card for integration into campus view,[35] Figure 9-. This data is read by BMS(NAE) network controller using a local network communication medium at airport and field server which is the protocol converter supplies data to the centralized control system (ADX) to be visualized by SCADA system.
In addition, BMS has screens to visualize the elevators, mats, stairs and boarding bridges in real time.

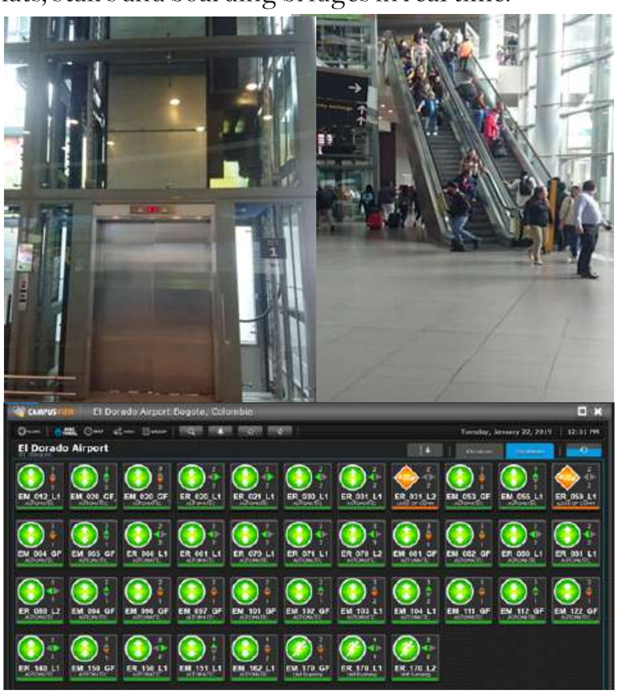

Figure 9. El Dorado Airport, Stairs, elevators and integrated stairs and gangways system at El Dorado airport. [42]

In the integration to the Metasys® system there are the BOARDING BRIDGES or better known as "FINGER"; each one can be considered a mobile bridge that extends from the terminal gate to the aircraft gate [43], -Figure 10- here can be found supervision and monitoring to variables which provide bridge status information. The process of communicating signals and centralizing them starts from the bridge itself, where an Allen Brandley® Compact logic PLC, reference L23E [44], is available, having the possibility of being connected through an Ethernet port to a main switch by means of an RJ45 cable. This PLC also has an RS232 serial port available, but due to factors such as distance from the controller to monitoring station [45], the system uses Ethernet network, being here the most appropriate for this type of applications.
The bridge also takes signals from other variables through the 1734A expansion module [46], designed to handle both digital inputs and outputs (dry contacts) and analog signals (variable voltages of 0-10 VDC or resistive signals), being sent and centralized in a Data Center where it reaches a Field Server which acts as a gateway that allows different devices using different protocols to communicate with each other. In this way, Ethernet (TCP/IP) signals coming from the bridge are taken and converted to Bacnet IP, and later they are sent through physical cabling to the network controller who takes the information and sends it to the ADX for its visualization. These network engines also have a FC Bacnet MS/TP bus where it can also gather data coming from controllers installed in the terminal, it has input and output ports for connecting sensors and actuators directly on the controller.

Figure 10. El Dorado Airport Terminal 1. [43]

4.8. Plumbing

This system has an interface that monitors equipment status of network pumps –Figure 11-, rainwater pumps [47], sewage pumps [48], water infiltration pumps, through dry contacts that are activated when any of those pumps in different systems present a failure, or tank exceeds the level of filling or emptying,-The field controller (FEC+IOM) monitors signals provided by

34 Criteria for elevator, escalator, moving walks and electric door inspection.
35 SCADA system visualization software for equipment

plumbing panels, through MS/TP Bacnet communication, and transmits data to network controller (NAE), using RS-485 communication, MS/TP Bacnet protocol 38.400 Baud, by connecting local network LAN [49] Airport, this system provides data to the ADX central control system and is displayed in SCADA.

Figure 11. El Dorado Airport Plumbing System Terminal 1. [47]

4.9. BHS

Airport baggage handling is a complex process; the modern BHS [50] baggage system installed at El Dorado Airport -Figure 12- has the capacity to transport an average of 7,200 bags per hour; it has conveyor belts for national, international and oversized baggage [51]. For baggage analysis and security, it has bag tag[36] printers with the corresponding application software, computer equipment, image analysis workstations, radios and communication equipment, and X-ray machines [52] Model MVT-HR 1000-10001-HR.

An OPC Interface (OLE for Process Control) is used for integration with Metasys® system, [53]. This Fieldserver device reads data from the BHS Server (OPC) and converts it to Bacnet IP protocol; this data is read by the network controller (NAE) and in turn this provides data to the central control system (ADX) to be visualized in SCADA.

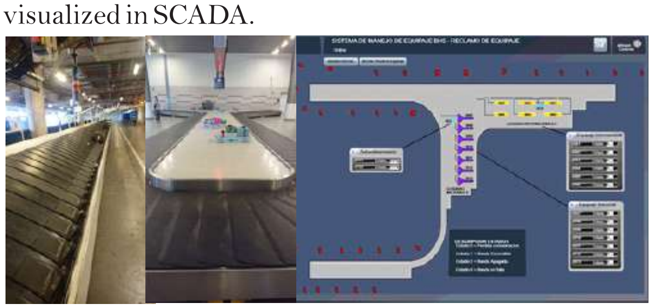

Figure 12. El Dorado Airport BHS system Terminal 1. [51]

4.10. SACS

For its operation it uses a software called P2000® version 3.11. The system has an integrated web browser that allows users to access the platform from a central or remote access through devices connected to Internet. It is a graphic interface system where the Access control system operates; it is a security product developed by Johnson Controls® company, it runs on a virtual machine that resides on xenserver [37] servers. The redundancy application is called ever Run MX from Marathon[38], which allows the availability of the application along all time, it works on a Windows Server system and has workstations according to the employee's profile. On the software application runs a SQL Server 2008 database where all the records of the airport users are stored, is an intelligent system of recognition and authentication of Binary, Biometric and Wigand[39] codes that allows entry to those people who have programmed cards / key numbers and pre-installed fingerprints to ensure access to entries and exits of the restricted areas of El Dorado Unified Passenger Terminal [54] - Figure 12.For its integration to BMS, it uses existing RS Ethernet port RJ 45 communication protocol in SACS server, local network airport communication media, sending information to ADX centralized server to be visualized in SCADA as system supervision, Figure 13.

Figure 13. El Dorado Airport SACS system, Terminal 1. Source: own.

5. Conclusions

In the air terminal, not only is the technological integration of different systems taken into account, but also a process is adapted in conjunction with airport operations [55], which is carried out by qualified personnel responsible for guaranteeing better results in integrated air conditioning systems, electrical systems, fire prevention networks, vertical and horizontal systems for passenger transport, plumbing, baggage handling, access controls and other systems.

Building Management System -BMS- at El Dorado International Airport is a paradigm that is planned and structured in detail. In this sense, different airport processes are considered effective when they comply with technical and installation standards, therefore,

36 Boarding card printer
37 Virtual Managed Server Platform.
38 Industry software based fault tolerant solution for multiple symmetrical processes.
39 Magnetic effect for data encoding or decoding.

they guarantee that systems integrated into the airport in Metasys® software are effective when at any moment in time status is consulted in real time and visualized in SCADA. To this end, it is necessary to comply with regulatory norms and industry standards established by (ASTM) American Society for Testing of Materials [56] and (ANSI) American National Standards Institute [57], Building Industry Consulting Service International (BICSI) [58], Institute of Electrical and Electronic Engineers (IEEE) [59], OSHA: Occupational Safety and Health Agency [60], among others.

Integration in BMS regarding communication systems should be supported by market standards that handle open communication protocols [61] allowing its evolution in a simple way, without having to introduce significant structural changes that affect airport operation [62] concerning air conditioning, electrical, fire detection, dry extinguishing, vertical and horizontal transportation, plumbing, baggage handling and access control systems integrated to Metasys® software seeking to improve day by day with respect to new technological advances found in global market, [63].

Savings obtained with an integrated system in terminal are not only seen in its economic dimension, but also in the positive impact it produces on the environment [60] compared to energy savings at the airport, as this is a worldwide trend in other airports around the world, [64].

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