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AUTOMATION SYSTEM SIGNAL LIST FORMATTING AND THE PRINCIPLES OF AUTOMATION CONFIGURATION

Master's Thesis

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AUTOMAATIKASÜSTEEMI SIGNAALINIMEKIRJA VORMISTAMINE JA AUTOMAATIKA KONFIGURATSIOONI SEADISTAMINE

Magistritöö

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Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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Abstract

Nacos Valmatic Platinum is an integrated automation system (IAS) for marine vessels developed by Wärtsilä Valmarine. Currently there is no standard I/O list and each client decides how the I/O list will be formatted. The aim of this thesis is to develop a format that could be used as a standard. I/O list format is combined by analysing different I/O list formats, comparing the contents of each I/O list and by investigating the requirements of different users. In addition to the format, the thesis provides conceptual model of a database, that would generate configuration files for Valmatic automation system.

This thesis is written in English and is 59 pages long, including 7 chapters, 5 figures and 15 tables.

Annotatsioon

Nacos Valmatic Platinum on integreeritud automaatikasüsteem (IAS) laevadele, mis on arendatud Wärtsilä Valmarine poolt. Hetkeseisuga puudub standardne I/O nimekiri ja iga klient otsustab kuidas I/O nimekiri vormistatakse. Käesoleva töö eesmärk on arendada formaat, mida saaks kasutada standardina. I/O nimekirja formaat defineeritakse läbi erinevate I/O nimekirja formaatide analüüsimiste, sisu võrdlemiste ja erinevate kasutajate vajaduste uurimise. Lisaks standardse formaadi defineerimisele esitab lõputöö konseptuaalse mudeli andmebaasist, millega saab genereerida automaatika konfiguratsiooni faile Valmatic'u automaatika süsteemile.

Lõputöö on kirjutatud inglise keeles ning sisaldab teksti 59 leheküljel, 7 peatükki, 5 joonist, 15 tabelit.

List of abbreviations and terms

DPI	*Dots per inch*
TUT	*Tallinn University of Technology*
I/O	*Input / Output*
PLC	*Programmable Logic Controller*
SCADA	*Supervisory Control and Data Acquisition*
FC	*Function code*
SQL	*Structured Query Language*
HVAC	*Heating, Ventilation, and Air Conditioning*
PMS	*Power Management System*
ESD	*Emergency Shut Down*
PAC	*Programmable Automation Controller*
DBMS	*Database Management System*
DG	*Diesel Generator*
ISA	*Instrumentation Symbols and Identification*
OPC	*Open Platform Communications*
VDR	*Voyage Data Recorder*
IP	*Internet Protocol*
IAS	*Integrated Automation System*
ISA	*International Standards on Auditing*

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1 Introduction

An I/O list, commonly also referred to as instrument or signal list, is a document containing a list of signals which serves as an input or output for a control and monitoring system [1]. It describes programs, operations and data, that is being transferred between two or more systems, as well as gives an overview of work scope. It is commonly presented in the form of a table and the number of signals and types of data included varies heavily between different projects.

The I/O list is used for setup, configuration and installation of individual components in addition to completing project related documentation. The I/O list will be updated continuously throughout the project phase. After the project handover, the I/O list holds the latest details in order to do maintenance for the system.

Currently there are no standardized I/O lists and the format is generally agreed upon within the organization. This means extra expenses for automation vendors and other parties alike, since each project with a new client means extra configuration setup work. In addition, with a strict formatting of the I/O list, general tools could be automated further to be less dependent on the user.

The main benefactors in using formatted I/O lists are the automation provider and the client. For the automation provider, a generalized signal list would essentially mean the possibility to fully automate the import and export processes as well as easier fault-finding in an early stage of the project. For clients, a formatted I/O list means some extra work in relation to setting up the system to comply with the new format. However, in the long run, it would decrease costs as the standard becomes more familiar and more versatile due to shorter preparation times.

2 General overview of I/O list

The I/O list contains several types of data used by different actors. In order to create a well formatted I/O list, all the actors and the requirements of each user must be established. Each system, that includes communication to the automation system, provides documentation, such as P&ID-s. The information gathered from the documentation is vital to the creation of the I/O list.

2.1 Preparation of I/O list

I/O list is commonly prepared by the automation coordinator after reviewing different system descriptions and documentation. For each type of mechanical equipment, such as pumps, fans, circuit breakers, compressors and engines, one or more signals are included. After defining and filtering the required signals, combining signals from subsystems and adding missing information, the I/O list is published.

This document is then shared with various project related professionals, such as electricians, cable installers, system engineers, operating personnel, test personnel and automation engineers. These professionals can be grouped as actors and the whole process is indicated on figure 1 on the next page.

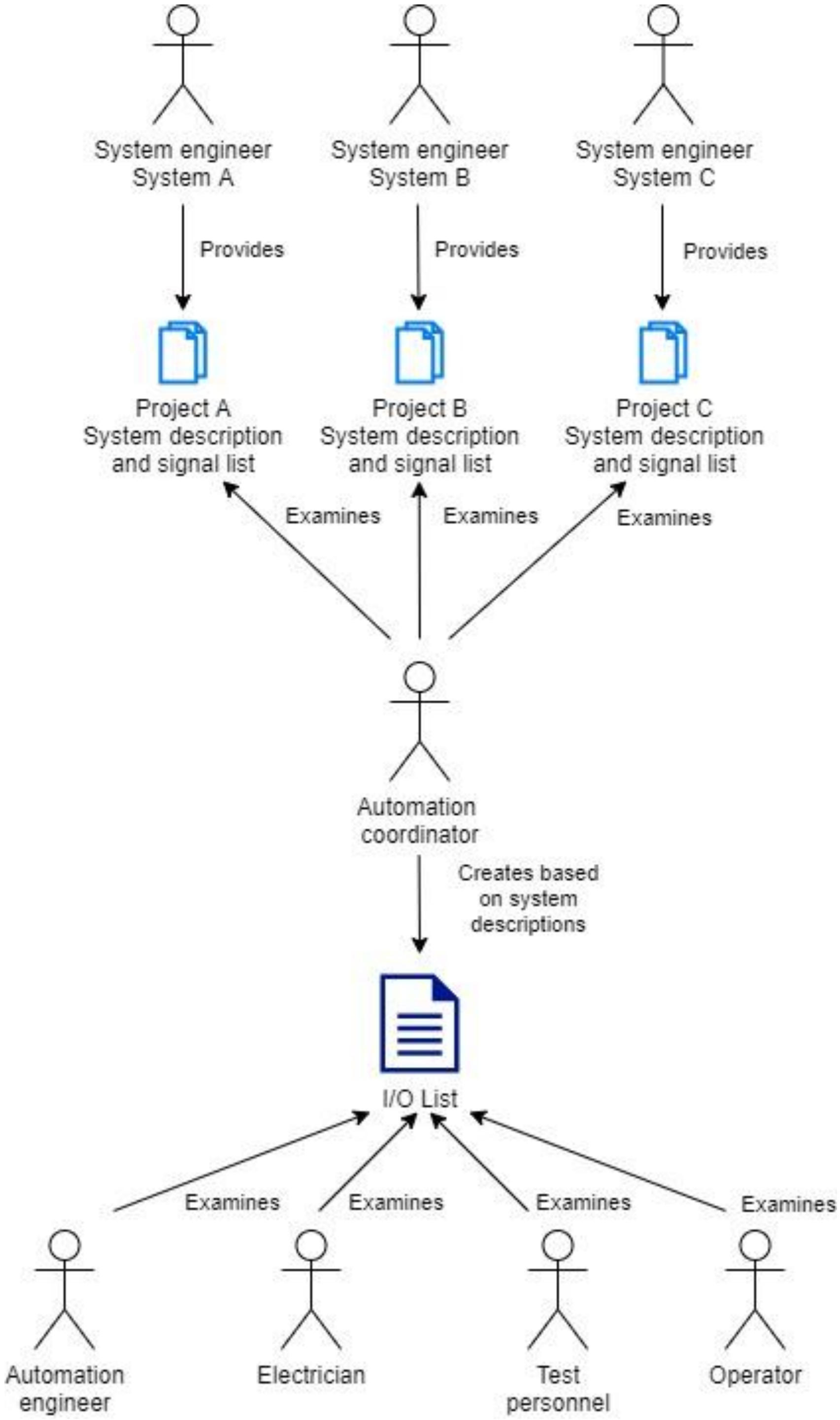

Figure 1: Preparation and distribution between actors of I/O list

2.2 Using I/O list by automation systems

A test environment for this project is a SCADA type automation system called Wärtsilä NACOS Valmatic Platinum. The system consists of I/O cards and I/O racks for hard-wired signals, which are connected to programmable application controllers, called PAC-s. Besides connection to hard-wired signals, the PAC-s are also connected to external devices over serial lines, as well as to MFD-s, which serve as operation and monitoring stations. Overview of the Valmatic system can be seen on the figure 2 below.

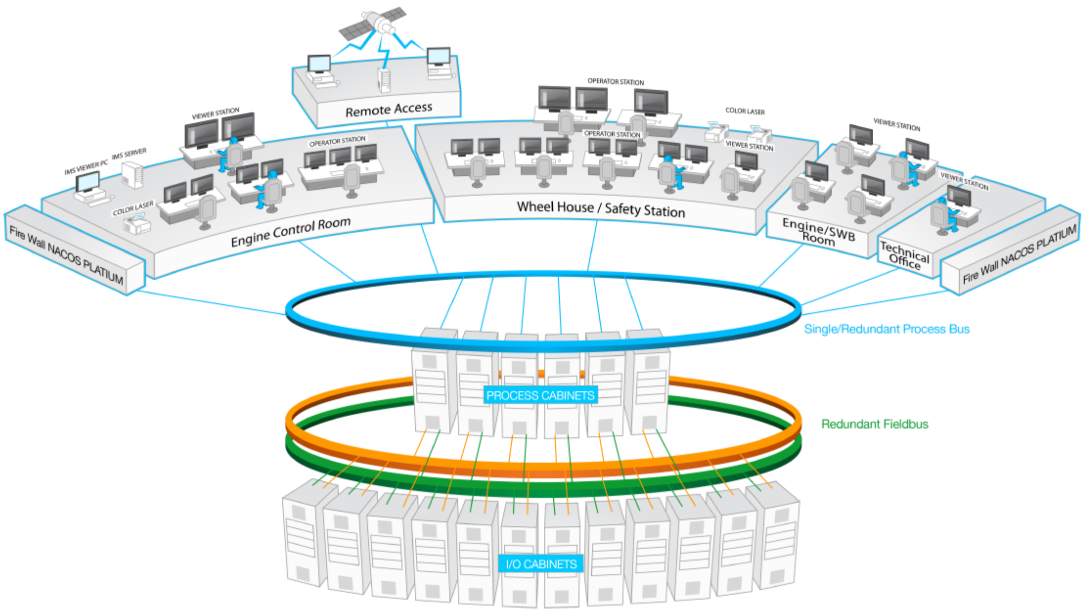

Figure 2: Overview of the Valmatic system

All the data about signals, necessary to set up the automation system configuration, must be included in the I/O list. In the case of bigger SCADA systems, for example cruise ship automation systems, the numbers of I/O signals can easily exceed 25000. For each signal, there can be up to 150 parameters. For cruise ship automation, the high number of signals comes from different systems and subsystems located all over the vessel.

Information from the I/O list is used by Valmatic automation engineers in order to set up the necessary configuration. Setting up requires information about communication, functionality, monitoring and control of each signal. Every missing parameter means additional work investigating system descriptions in order to finalize the setup.

The I/O list is also used during the testing phase. Every signal is tested at least once after the final adjustment has taken place. It is not uncommon that during the testing phase, the design of the system, together with the I/O list and automation configuration, is modified.

2.3 Signals over different electrical interfaces

The signals transmitted in the IO-list can be largely divided between two groups: digital communication or hard-wired connections. For hard-wired signals, each sensor/actuator is directly wired and acts as either an input or an output. Hard-wired connections are considered the optimal choice for critical signals, due to more fool-proof and simple design. The major downside is, that the setup involves more cabling and installation.

In case of digital communication, data is being transferred over serial interface. Most common serial interfaces standards are RS-232, RS-422 or RS-485 for RTU, Profibus protocol and over ethernet cable for TCP/IP connections. The advantages of using digital communication include less time for installation, more flexibility regarding data management, as well as easier operability and maintainability. Parameters vary between different serial interface standards.

These features are achieved by collecting data to a PLC in a centralized manner and in case of changes needed in the configuration, a change in PLC will suffice instead of making a change in wiring. However, the trade-offs for digital communication compared to hard-wired connections include difficult integration and setup process, compatibility issues, longer delay for receiving information, troubleshooting and cost.
For each electrical interface type, the I/O list contains different types of parameters.

Benefits and requirements of formatted I/O list
The main benefits of having standardised I/O format would be:

1. Reduced I/O list preparation time.
2. Reduced automation software configuration time.
3. Reduced documentation preparation time.
4. Reduced amount of human errors for preparing automation configuration.

5. Increased consistency, when continuously using and continuously improving one I/O list template.

Upon a fully automated process for preparing configuration files for automation, the goal is to lower manual labour for the automation engineer, as well as lower the project database and related documentation preparation time. Furthermore, new concepts, such as early level troubleshooting, various documentation and overviews can be set up automatically with the help of additional tools in case of a strict I/O list format.

The main drawback of using a formatted I/O list is the extra work introduced, when changing the I/O format. Instead of using a new format, companies often preferred to continue working on the old and familiar setup. Changing to a new I/O list format also requires a new set of tools, used to either fill the I/O list or extract information from it.

The main requirements for formatted I/O list include:

1. Fulfils the requirements of all involved actors.
2. I/O list is required to contain more parameters and fields than necessary, in order to be prepared for unique data specifications (such as NMEA [2]).
3. Data and parameters included is required to be understood explicitly between different parties.
4. Troubleshooting the I/O list is required to be as easy as possible.
5. The configuration of Valmatic automation system is required to be as easy as possible and where possible, applicable for other automation systems as well.

3 The requirements of I/O list users

I/O list is used by several different actors working with various systems. The I/O list is used throughout the project design and building phase and after delivery. the project phase for maintenance. System engineer, automation coordinator, automation engineer, electrician, test personnel and operator are among the actors, who set the requirements for the I/O list format.

Not only is it important to define the I/O list standardised parameters but also to set the parameter specific limitations. This is required to make the data understandable for people as well as computers [3]. One example of limitations is I/O card number. In the test system used, the maximum number of I/O cards per motherboard is 10. If the signal is of hard-wired type, the value in this cell should be a value between 1 and 10 in order not to create any conflicts when importing the configuration to the database.

Some actors use the I/O list directly, while others only use certain parts of the I/O list. Due to this, I/O list parameters are often segregated into separate parts. The separation of I/O list is described in further detail in the fifth chapter of this thesis.

3.1 System engineer

Different system engineers work with different systems. For each of these systems, inputs and outputs connected to the automation system are defined in the I/O list. System engineer provides all possible signals for the automation coordinator and the coordinator defines the signals to be connected.

The main requirement for a system engineer is that the necessary information can be filled in a structurally correct way. This includes various communication, cable, identification and other related parameters. Not only is it important that the correct parameter fields are included in the I/O list, but character limitations set on parameters should not contradict with included data.

3.2 Automation coordinator

Automation coordinator is usually the responsible person for the I/O list and the format. Any modification to the format should be approved by him. Coordinator initially confirms the I/O list structure suitable for all other actors and makes project-based modifications where needed.

Automation coordinator is the only actor who can edit the information in the I/O list. In case there are multiple people modifying the I/O list, the signal parameters must include identification of the last automation coordinator to make changes. Automation coordinator receives overview of available signals as stated in contract from the database, as well as feedback for any possible mistakes.

3.3 Automation engineer

Automation engineer is the responsible person for setting up the configuration for the automation system. He uses the I/O list as a whole and there are only some parameters that are out of his scope of work (cable information for example).

As stated in chapter 2.2, setting up the configuration requires information about communication, functionality, monitoring and control of each signal. In addition, each field used as an automation configuration parameter, should be importable without editing. This is achieved by setting character type, length or value-based limitations to mentioned parameters.

3.4 Electrician

Electricians are responsible for connecting the cable correctly between multiple systems or between a system and a sensor. Electricians only use a small part of the I/O list, which is used to set up the connection.

The main requirement for electricians is that all information related to cable and connecting the cable is available. This includes information like cable number, type, pin numbers, cabinet number and terminals. The preferred layout includes at least three pin numbers, for power, output and ground.

3.5 Test personnel

Test personnel are responsible for testing the connection, functionality and monitoring of systems. For test personnel, not all information is required, but only the parameters describing the functionality and connection of both the automation system and the connected sensor or system.

Testing the automation system includes both monitoring and control. For example, if the correct signal name and ID displayed on the screen and following the correct steps after emergency shutdown of an equipment are taken care of.

3.6 Operator

Operator is a person who monitors and controls multiple systems with the help of automation systems. In addition, one of the tasks of the operator is to notify correct personnel, in case local action is needed. One of the examples is the case of a pipe leakage.

The main requirement for an operator is the possibility to track, identify and troubleshoot any problems related to signals in the automation system. Each system is monitored from one or more multifunctional displays. The operator monitors the event or alarm list and navigates between mimics to receive additional information or control equipment.

Since the number of these signals is in thousands, there is always a possibility that a message displayed in the automation system involves an unfamiliar system or status. In that case, I/O list is used to identify and track any equipment and items related to that signal.

4 Analysis of different I/O lists

In order to get an overview of how the I/O list should be formatted, instrument lists from different sources were analysed. These sources are collected from previous projects from various countries and companies.

Total of six unique I/O lists were analysed for this thesis. The links to I/O lists are included in Appendix 1. In the following chapters three of these I/O lists will be analysed together with detailed overview of the contents.

TAG, a unique identifier for each signal, used for various projects, is an eight- or ten-character ID that specifies the system (first 4 characters) and equipment (characters 6-9). In case equipment has more than one item, each item under this equipment has an extra ".XXXX" in the TAG, where X is the sequence number of the item under this equipment. System, equipment and item are each separated by a ".".

As an example, a pump with only one feedback signal has 9-character ID, meanwhile a pump with feedback and command for starting or stopping the pump has 14 characters. A sample signal of TAG, together with the definition, is presented in the "Example TAG identifier" table.

Table 1: Example TAG identifier

System	Equipment	Item	TAG
7021	0200	0002	7021.0200.0002

7021- Diesel generator 2

0200- Pre lubrication pump

0002- Start command

4.1 Project A I/O List

The I/O list for PROJECT A holds the least amount of information compared to other lists: only a total of 28 parameters and 4271 signals. The 28 parameters include the minimal amount of data that could be included in the I/O list. This small project is well suited for investigating what is the minimal amount of information needed.

4.1.1 Project A I/O list content overview

Following the unique identifier TAG, there are four numbered description fields. DESCRIPTION FIELD 1 and DESCRIPTION FIELD 3 columns both contain identical information about signal description with no limitation to character numbers. It is more than likely that one of these fields was originally meant to be used as an alternative option, for example a different language, but it was not used in this project.

DESCRIPTION FIELD 2 contains specifications for signals under the same system and equipment. Common fields under this field are opened, stopped, start and stop command. DESCRIPTION FIELD 4 was left unused and the purpose is unclear.

INSTRUMENT CODE, also referred to as ISA code for process automation [4], field contains several character identifications where each character specifies the process type. For example, TICAHL means Temperature Indication Control Alarm High Low.

SENSOR RANGE MINIMUM and SENSOR RANGE MAXIMUM are used for automation monitoring and sensor range definition alike. RANGE UNIT defines a unit of measurement, to be displayed for the operator. These three fields define what kind of scale is available for monitoring analog signals.

SIGNAL TYPE defines the electrical connection type for the signal. For hard-wired signals sensor type, such as normally opened, normally closed (binary signals), 4-20mA and PT100 (analog signals), is specified. The unit of measurements for analog loops, such as 4-20mA or 24V, is specified in the column called SIGNAL UNIT. In case of s "SERIALXX" in case of serial interface connection and 'XX' represents the sequence number of serial interfaces.

SETPOINT column indicates what is the target value of an analog reading and is used for regulating purposes. In addition to setpoint, each signal has the following choice of alarm limits: LOW LOW, LOW, HIGH, HIGH HIGH. These alarm limits share the same activation time from the column DELAY and the field ALARM GROUP.

DISTRICT and AREA parameters indicate the physical location of sensor or activator. In case of multiple people, who edit the I/O list, DESIGN field is used to indicate who was the person responsible (system engineer for example) for that signal and CHANGED indicates who made the last edit. Together with these fields, DESIGN DATE indicates when the last change was made.

TBLOCK parameter is the same as TAG, but only contains system and equipment number (without ITEM field). CHANNEL is a parameter that defines the channel, where the wire will be connected to from the automation I/O card side.

The rest of addresses, such as PAC, motherboard and I/O card number are indicated in the field CARD. CARD parameter includes the PAC number, I/O rack and I/O card number. The very last parameter, CABINET indicates in which automation system electrical cabinet the I/O card is connected.

4.1.2 Project A I/O list example data

Table 2: Project A example data

TABLE FIELD	Example 1	Example 2	Example 3	Example 4
TAG	5121L012.1	5121X015.1	6311.011.1	6311.011.2
DESCRIPTION 1	FO STORAGE TANK LEVEL	FO STORAGE TANK OVERFLOW	LO TRANSFER PUMP1	LO TRANSFER PUMP1
DESCRIPTION 2	MEAS	ALARM	RUNNING	REMOTE
DESCRIPTION 3	FO STORAGE TANK LEVEL	FO STORAGE TANK OVERFLOW	LO TRANSFER PUMP1	LO TRANSFER PUMP1
DESCRIPTION 4				
INSTRUMENT CODE	LIALH	LAHH	XS	XS
RANGE MIN	0			
RANGE MAX	25			
RANGE UNIT	m			
SIGNAL TYPE	4-20	NC	NO	NO
SIGNAL UNIT	mA			
SETPOINT				
LIMIT HIGH	23.5			
LIMIT HIGH HIGH				
LIMIT LOW	2.1			
LIMIT LOW LOW				

DELAY	5			
ALARM GROUP	5	5	12	12
INFO				
DISTRICT			MCC2	MCC2
AREA				
DESIGN	ST	ST	ST	ST
DESIGN DATE	1/16/2015	1/16/2015	1/16/2015	1/16/2015
CHANGED	JTE	JTE	ST	ST
TBLOCK			6311.011	
CHANNEL				
CARD	1	10	3	1
CABINET	010203	010205	050102	050102

4.1.3 Project A I/O list analysis

In the example Project A, signal type "SERIAL" together with a sequence number is used. Serial indicates serial line communication meaning that many signals will be transferred over one cable and the sequence number of this serial line. For this project, the serial line parameters are represented only in a separated serial line interface list.

After inspecting the documentation related to this serial line, a few shortcomings were revealed. Such specifications including connection type (Modbus over TCP/IP this case), slave number, IP, register and bit numbers were used in documentation by vendors, but these were not included in the I/O list.

There were also missing parameters for hardwired signals. Using a single DELAY means that there is no delay separation for different analog limitations and binary signals. For analog signals with both high and low limits, for example tank level measurements, different delays are required for individual alarm limits.

In addition to missing alarm delays for separate alarm limits, sensor and automation range are not separated. Sensor and automation range values are not always identical: For example, in case of a tank level reading the sensor range might be 0-30m, while the tank height is only 22m. That means for values above 22m, sensor failure should be displayed on the automation system.

Unfortunately, this list does not contain enough information to set up the serial communication between two systems. Simply without specifying the mentioned information, it is not possible to set up a serial communication. This means extra manual labour spent on going through documentation, while filling in all the missing parameters.

Furthermore, problems related to hardwired signals will be examined during a later stage while the commissioning of the automation system. This means extra time spent on preparing and testing the modification in a situation where time is of the essence. In addition, there are no possible ways to present previously made modifications in a structurally correct manner in the I/O list.

On the other hand, this I/O list table is quite neatly structured and easy to comprehend. Due to the project's uniqueness and size, this type I/O list might be the easiest to deal with. More so, considering that there are no similar future projects planned and importing configuration again from a similar I/O list can be considered non-essential. However, this is not the case with standard projects, where the number of signals can exceed 25 000. For projects like these, a more thorough I/O list is needed in order to set up configuration automatically, as well as prepare documentation and reports.

4.2 Project B I/O list

The I/O list for Project B contains over seven thousand signals, separated between twenty different pages. One page contains information about all the hard-wired signals and for each of the ten systems connected via serial line communication, there is a separate page containing the details. In addition to multiple page setup, the data is heavily colour coded and the I/O list can seem rather overwhelming at first glance.

4.2.1 Project B I/O list hardwired signals content overview

In the hard-wired signals page, the first columns are called PROCESS1 and PROCESS2. PROCESS1 contains the word “HARDWIRED” in every single cell and PROCESS2 indicates the number and name of the subsystem. Next column, called ID, is a six-digit unique number and functions in a similar way as Tag from Project A.

TEMPLATE column specifies how the signal functions for the automation. For example, all signals that have not been grouped under one unit and do not have other functionality besides monitoring are called “Monit”. Other options include “Pump”, “DG” and “Valve”.

In addition to ID, this yard list also uses I/O ID, TAG and DEVICETAG. I/O ID is automatically generated from ID, the character “_” and sequence number of the particular signal under this item. TAG and DEVICETAG are filled in a similar manner, but the main difference between I/O ID and DEVICETAG is that there is no character limit. Extra characters are used to indicate the sensor type as well as item specific information (for example, DG number). ORDER cell specifies the sequence signal number under one item and is equivalent to the rightmost character of the DEVICETAG and I/O ID.

NAME and REMARK columns function identically DESCRIPTION1 and DESCRIPTION2 fields under the previous example. If there are no changes made for a signal, there will be a value “0” under REV column. Each time the signal is changed in the I/O list, REV value increments by one and the cells changed are highlighted.

CARD_TYPE field is used to define I/O card type for the automation number. CARD NUMBER and MODULE_ID are the same field as CARD for Project A, with only a minor difference in formatting. In addition, PAC_NO and FIC_NO parameters indicate PAC and FIC numbers in a separate column.

TERM1, TERM2, TERM3 and TERM4 are parameters for I/O card terminals and indicate how the wires from the sensor should be connected. IO_TYPE indicates if the signal is analog or binary and acts as an output or input to the automation. Values in this column are either BI, AI, BO or AO.

SCALING BLOCK further specifies the sensor type for analog signals, and it usually includes measurement unit and an indirect specification related to the corresponding range. For the next parameter SBLOCK_NAME, range for analog value in the automation system is specified as a numeric value, along with unit of measurement and the type of sensor. Common sensor types include 0-20mA, 4-20mA or PT100.

SIGNAL_TYPE further specifies if the input type is current, PT100 or voltage. SIGNAL_RANGE_MIN and SIGNAL_RANGE_MAX specify sensor range, while MIN, MAX and UNIT define the monitoring range and measurement unit for the automation system.

DECIMAL indicates the decimals to be displayed in the automation system. CAVO and IO_CABINET define the location and the name of the I/O cabinet. PAC, FIC and CARD are specified separately, unlike in Project A where this is defined under one parameter. CHANNEL parameter further clarifies where the wires will be connected in the automation system.

ELCONNTYPE defines if the sensor type is either binary or analog and if it acts as an input or an output for the automation system. GDID_1 identifies the primary mimic, where the signal is displayed in the automation system.

All possible alarm groups are defined as parameters ALGROUP1, ALGROUP2, ALGROUP3 and ALGROUP4. Alarm groups indicate the systems or subsystems, related to each alarm. PRIORITY field indicates the importance of signal, where one is the most critical alarm and nine is a regular status feedback signal.

ALTEXT, NORM_TEXT and EVENT_TEXT contain the same information described in the previous section, but as a text value instead of a numeric value. SUPPRESSION parameter indicates if the alarm should be under certain situations. For example, fuel low flow alarms are suppressed when the engine is not running.

High, high high, low and low low alarm limits are defined under ALIMITH, ALIMITHH, ALIMITL and ALIMITLL respectively. For each of the alarms, a separate delay is included under parameters HH_DELAY, H_DELAY, L_DELAY and LL_DELAY. NOTE parameter defines the process in a similar manner as ISA instrumentation code.

4.2.2 Project B I/O list serial line signals content overview

The serial line information is stored in the same I/O list but under a different page. The parameters vary between serial lines depending on which type of interface was used.

For serial line signals, first two cells are filled in alternatively compared to hardwired signals: PROCESS1 contains the number and PROCESS2 indicates subsystem (for hard-wired signals, this information is concatenated under a single cell).

However, a few parameters that could be used for hardwired signals as well, were only used for serial interfaces. These parameters include MACH_GRP, which defines the machinery group and UDFB_ID, which defines the Valmarine automation logic template. Furthermore, in addition to alarm limits and delays, some serial lines include separate priorities for analog limit alarms signals as parameters LLPRIO, LPRIO, HPRIO and HHPRIO.

4.2.3 Project B I/O list example hardwired signal data

Table 3: Project B example data

Table field	Example 1	Example 2	Example 3
PROCESS1	HARDWIRED	HARDWIRED	HARDWIRED
PROCESS2	03 LUBRICATION OIL	03 LUBRICATION OIL	03 LUBRICATION OIL
ID	63311	63311	63311
TEMPLATE	PMP01	PMP01	PMP01
I/O ID	63311_1	63311_2	63311_3
TAG	6311PMP11	6311PMP11	6311PMP11
DEVICETAG	6311PMP11.1	6311PMP11.2	6311PMP11.3
ORDER	1	2	3
NAME	LO TRANSFER PUMP1	LO TRANSFER PUMP1	LO TRANSFER PUMP1
REMARK	RUNNING	REMOTE	START
REV	0	0	0
CARD_TYPE	VM-BI.08-SUP-E	VM-BI.08-SUP-E	VM-RO.08-230
CARD NUMBER	050102	050102	050101
MODULE_ID	0501_02	0501_02	0501_01
TERM1	X1:5	X1:7	X1:1
TERM2	X1:6	X1:8	X1:2
TERM3	--	--	--
TERM4	--	--	--
PAC_NO	05	05	05
FIC_NO	01	01	01
IO_TYPE	DI	DI	DO
SCALING BLOCK	-	-	-
SBLOCK_NAME	--	--	--
SIGNAL_TYPE	--	--	--
SIGNAL_RANGE_MIN	--	--	--
SIGNAL_RANGE_MAX	--	--	--
MIN	--	--	--
MAX	--	--	--
UNIT	--	--	--
DECIMAL	--	--	--

CAVO	C03-6300-6	C03-6300-6	C03-6300-6
IO_CABINET	9311AS07	9311AS07	9311AS07
FIC	01	01	01
CARD	02	02	01
CHANNEL	03	04	01
ELCONNTYPE	BI	BI	BO
PAC	PAC05	PAC05	PAC05
GDID_1	4.12	4.12	4.12
ALGROUP1	12	12	12
ALGROUP2			
ALGROUP3			
ALGROUP4			
PRIORITY			
ALTEXT			
NORM_TEXT	Stopped	Stopped	Off
EVENT_TEXT	Running	Running	On
SUPPRESSION			
ALIMITH			
ALIMITHH			
ALIMITL			
ALIMITLL			
HH_DELAY			
H_DELAY			
L_DELAY			
LL_DELAY			
NOTE			

4.2.4 Project B I/O list analysis

Pages of project B I/O contain various overview information, automation configuration specifics about automation system engineering units, exported automation configuration data, alarm texts, scaling blocks, as well as deleted signals and other information. All of this is included in a twenty-one page I/O list.

The format of the I/O list is not consistent and varies between pages. Without a list of contents, tracing signal information is difficult and various unexplained color-coding makes it burdensome to initially comprehend.

Although the I/O list for project B contains more parameters than project A, it is not necessarily more thorough. Parameters CARD NUMBER and MODULE_ID in project B I/O list contain almost identical data, which are also defined under PAC_NO, FIC, CARD and CHANNEL. For parameters SBLOCK_NAME, SIGNAL_RANGE_MIN and SIGNAL_RANGE_MAX unnecessary redundancy occurs in a similar way.

On the other hand, the I/O list was prepared with a few parameters not included in project A. These parameters include the possibility of multiple alarm groups or alarm subgroups in case needed. Additionally, there are possibilities to define separate delays and priorities for low low, low, high and high high alarms.

Parameters like MACH_GRP, UDFB_ID, LLPRIO, LPRIO, HPRIO and HHPRIO are only included for several serial lines. These parameters should be applied for hardwired signals as well, since this information is not limited to the configuration of serial lines.

Information not included with the I/O list of project B, involves parameters related to cable information and any related drawings. The parameters used in the I/O list are mainly focused on the automation configuration aspect. Due to missing parameter defining signal polarity and related documentation, the I/0 is not well suited for electricians.

The I/O list for project B gives a better overview of what parameters a standard I/O list should contain. Compared to project A, more detailed parameters for the configuration of automation were included. Possible improvements for project B I/O list include a more standardised layout of the I/O list and the reduction of redundant data.

4.3 Project C I/O list

The I/O list for Project C contains roughly five thousand signals with thirty-seven parameters. Majority of the information included is in English, with the few exceptions that are included in Finnish. The I/O list consists of one page, where both hard-wired and serial I/O.

4.3.1 Project C content overview

A lot of parameters for this I/O list have been defined in chapters 4.1.1 and 4.2.1. Table 4: Project common data presents the common parameters and what is the parameter name under project A and project B. All non-common parameters are also defined under this paragraph.

Table 4: Project C common data

Project C	**Project B**	**Project A**
DESCRIPTION_EN	NAME	DESCRIPTION 1
DEVICE FUNCTION_EN	REMARK	DESCRIPTION 2
ITAG	NOTE	INSTRUMENT CODE
EQUIPMENT	DEVICETAG	
ENGTAG	TAG	
SCALE_L	SIGNAL_RANGE_MIN	RANGE MIN
SCALE_H	SIGNAL_RANGE_MAX	RANGE MAX
AL_LL	ALIMITLL	LIMIT LOW LOW
AL_L	ALIMITL	LIMIT LOW
AL_H	ALIMITH	LIMIT HIGH
AL_HH	ALIMITHH	LIMIT HIGH HIGH
DELAY		DELAY
UNIT	UNIT	SIGNAL UNIT
OCP_AL_GROUP		ALARM GROUP
AL_PRI	PRIORITY	
CAB	IO_CABINET	CABINET
CARD		CARD
CH	CHANNEL	CHANNEL
CHANGED		DESIGN DATE
RA_USER		CHANGED
AREA		AREA
NOTES		INFO

REC parameter is the unique identifier for project C. REC consists of six or seven characters and the first three characters are from the first characters from the EQUIPMENT parameter. Remaining characters are sequence numbers, not related to the rest of the parameters.

DESCRIPTION_FI and DEVICE FUNCTION_FI parameters contain the same information as DESCRIPTION_EN and DEVICE FUNCTION_EN (see table 4), but in Finnish language.

LOOP defines the register for Modbus communication. BIT is used to define which register bit should be controlled or monitored.

AREA MAIN defines the system connected to the signal and AREA SYSTEM further specifies the subsystem. For example, AREA MAIN can be defined as the main engine and AREA SYSTEM is defined as the first main engine.

INTERFACE defines the type of system. Some of the systems defined in INTERFACE, including the voyage data recorder (VDR) or dynamic positioning (DP)[5], use specific communication standards like NMEA[2], UKOOA [5] and IMCA [5]. The communication specifics of these interfaces are often defined on a separate document.

MAKER is the vendor providing the delivery of a system. The document code, for example for P&ID or any other drawing provided by the vendor, is defined in DWG parameter.

SENSOR TYPE defines the code of a switch or sensor type. The sensor type definition is different from the previous I/O lists by indicating the physical part used instead of measurement related info.

ACTION defines the critical level, where automation control takes preventive measures. For example, if one of the winding temperatures of any generator exceeds 160 °C, the engine will be shut down. SIGPOLARITY defines normally opened contacts as “O” and normally closed contacts as “C”.

REV indicates the revision code of modification of the I/O list. Revision code is overwritten when there is a change in signal parameters. REV_REMARK contains “added” if the signal was not present in the last revision of the I/O list and describes the modification made.

4.3.2 Project C example data

Table 5: Project C example data

REC	512121	512151	633101
DESCRIPTION_FI	PÖ VARASTOTANKIN PINTA	PÖ VARASTOTANKIN YLIVUOTO	VÖ SIIRTOPUMPPU 1
DEVICE FUNCTION_FI		HÄLYTYS	KÄY
DESCRIPTION_EN	FO STORAGE TANK LEVEL	FO STORAGE TANK OVERFLOW	LO TRANSFER PUMP1

DEVICE FUNCTION_EN	MEAS	ALARM	RUNNING
ITAG	LIALH	LAHH	XS
LOOP			
BIT			
EQUIPMENT	5121LIALH12	5121LAHH15	6311.011
ENGTAG			
AREA MAIN	Pipes	Pipes	Pipes
AREA SYSTEM	Fuel Oil	Fuel Oil	Lub Oil
INTERFACE			
MAKER	AUTRONICA		
SENSOR TYPE	MBT5250		
SCALE_L	0		
SCALE_H	25		
AL_LL			
AL_L	2.1		
AL_H	23.5		
AL_HH			
ACTION			
DELAY	5		
UNIT	m		
OCP_AL_GROUP	5	5	12
AL_PRI			
SIGPOLARITY		C	O
CAB	9311AS01	9311AS01	9311AS07
CARD	010203	010205	050102
CH	1	10	3
REV	B	B	A
REV_REMARK	ADDED	ADDED	ADDED
CHANGED	1/16/2015	1/16/2015	1/16/2015
RA_USER	JTE	JTE	ST
AREA			

DWG	D.385.5610.501.008		
NOTES	Muutoshistoria: Desc., Area, Dwg(29.1),		ANALOG
REC	561002	824112	632234

4.3.3 Project C I/O list analysis

Project C I/O list is formatted in a similar manner as Project A I/O list. One major formatting difference between the two I/O lists is that project C has included the serial data communication. However, the serial line information is missing the Modbus function code specification, the IP address and COM port specification for project C.

The revisional information is formatted in a more organized way. The REV parameter specifies the latest revision that included a modification for the signal. In case of a new revision, REV_REMARK is not replaced, but instead the new modification information is added to the parameter together with a date stamp. These small changes improve the overview of changes made.

5 Standardized I/O list

The three I/O lists included in this analysis all had different layouts. Major differences occurred regarding how serial data information was defined. For project A, the serial data was not included in the I/O list. For project B, each serial interface was presented on a different page and in project C serial data was partially included in the single page I/O list file.

The only I/O list divided into subcategories was Project B. However, the subcategories were not structurally divided and included a lot of unnecessary information. Without overview, the contents of the I/O list were scattered around.

The I/O list could be separated into subcategories under a different criterion. In order to analyse all other data, the following information subgroups will give a better overview of the document:

1. Tag
2. Hard-wired IO
3. Serial IO
4. Signal common
5. Cable
6. General

The subcategories use the same unique identifier, a value combined from the "system", "equipment" and "item" from signal category. Each of the three mentioned categories is formatted as a 4-character ID code and these items together (and separated by a ".") form the UNIQUE TAG.

In smaller projects, for example PROJECT A, Unique tag is mostly combined only from System tag and equipment number. Item number is added where necessary (if more than 1 signal comes from the same system but different item).

Following chapters will describe the subcategories of one possible standardized I/O list and its contents. The finalized complete I/O list format, together with example data and content overview table are included in appendix 2.

5.1 Tag

The main objective of tag category is to define every point of signal configuration when it comes to displaying monitoring and control. As mentioned in the beginning of this chapter, “system”, “equipment” and “item” define the TAG. Each of the values entered has a number with the value between 0 and 9999.

In addition, “TAG NAME” field provides a short description of the signal. “REC” serves as an alternative to “TAG” ID and using this is optional. Automation configuration-based specifics, such as alarm priorities, delays and limits will be specified under this category. Most often, four different alarms can be used:

- Low low- Critical, usually high priority alarm event triggered by a very low value reading
- Low- Regular alarm event triggered by low value reading
- High- Regular alarm event triggered by high value reading
- High high- Critical, usually high priority alarm event triggered by a very high value reading

TAG NAME provides descriptive information about the equipment. TAG FUNCTION is used to describe binary signal text for monitoring channels or specify the functionality of output.

COMMON TAG functions include “Running”, “Stopped”, “Start command” and high alarm. TAG DESCRIPTION is up to a five-letter code for describing the used sensor. For example, TAH stands for Temperature Alarm High.

In addition, there are a few extra fields for analog signals:

- TAG MIN- Minimum display range
- TAG MAX- Maximum display range
- TAG UNIT- Unit of measurement
- TAG DECIMAL- Number of decimals to be displayed

Finally, each signal is assigned under a machinery group in the parameter field MACH GROUP. Machinery groups are required to specify control rights between different operating locations. In a similar manner to machinery groups, alarm groups indicating subsystems are specified under TAG category. The very last parameter, MIMIC_1, indicates the main mimic page in operator station.

Table 6: Standardized tag subgroup

FIELD	**CATEGORY**	**DESCRIPTION**
TAG	ALL	Signal ID, in form of "SYSTEM"."EQUIPMENT"."ITEM"
SYSTEM	TAG	Subsystem identifier where the signal belongs to
EQUIPMENT	TAG	Equipment identifier where the signal belongs to
ITEM	TAG	Signal number under the equipment
REC	TAG	Yard internal signal ID (if needed), not used by IAS
TAG NAME	TAG	Signal description/Equipment description (limited)
TAG FUNCTION	TAG	Instrument code/Description of signal Function
TAG DESCRIPTION	TAG	Signal description/Equipment description, not used by IAS
TAG MIN	TAG	Analog display range - Minimal value (presented on the operator stations)
TAG MAX	TAG	Analog display range - Maximal value (presented on the operator stations)
TAG UNIT	TAG	Analog display unit (presented on the operator station)
TAG DECIMAL	TAG	Analog display precision - No. of decimals (presented on the operator station)
LOW LIMIT LL	TAG	Analog display alarm limits - Low Low alarm
LOW LIMIT L	TAG	Analog display alarm limits - Low alarm
HIGH LIMIT H	TAG	Analog display alarm limits - High alarm
HIGH LIMIT HH	TAG	Analog display alarm limits - High High alarm
DELAY LL	TAG	Analog display alarm delays - Low Low alarm
DELAY L	TAG	Analog display alarm delays - Low alarm
DELAY H	TAG	Analog display alarm delays - High alarm
DELAY HH	TAG	Analog display alarm delays - High High alarm
DELAY	TAG	Binary display alarm delay
PRIORITY LL	TAG	Analog display alarm priorities - Low Low alarm (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)

PRIORITY L	TAG	Analog display alarm priorities - Low alarm (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)
PRIORITY H	TAG	Analog display alarm priorities - High alarm (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)
PRIORITY HH	TAG	Analog display alarm priorities - High High alarm (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)
PRIORITY	TAG	Binary display alarm priority (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)
MACH GROUP	TAG	Machinery group (separation in order to transfer control for specific part of system to different control location)
ALARM GROUP	TAG	Alarm group
MIMIC_1	TAG	Number of the primary mimic, where the signal is presented

5.2 Hard-wired I/O

Hard-wired I/O table provides the specifics of the connection between the automation side and sensor. The location of the I/O card is given under the CABINET field. Signal station, Rack, I/O rack, card and channel further specifies the number of equipment used in the data exchange process. Each signal must have an individual combination of the mentioned equipment number since each sensor is connected via separate wire.

In addition, Card type column specifies which I/O card is used. For some sensors, up to four wires are used and for each wire, there is a separate Terminal number column. All information stored in the Hard-wired I/O table will be used by electricians in order to connect sensors to the correct I/O card.

Table 7: Standardized hard-wired I/O subgroup

FIELD	CATEGORY	DESCRIPTION
TAG	ALL	Signal ID, in form of "SYSTEM"."EQUIPMENT"."ITEM"
CABINET	HW-IO	Cabinet where the signal is connected to on IAS side
SIGNAL STATION	HW-IO	PAC where the signal is connected to
RACK	HW-IO	IO-rack number where the signal is connected to (hardwired signals only)
CARD	HW-IO	IO-card number where the signal is connected to (hardwired signals only)

CH	HW-IO	IO-channel number where the signal is connected to (hardwired signals only)
TERMINAL 1	HW-IO	IO-channel Terminal 1
TERMINAL 2	HW-IO	IO-channel Terminal 2
TERMINAL 3	HW-IO	IO-channel Terminal 3
TERMINAL 4	HW-IO	IO-channel Terminal 4
CARD TYPE	HW-IO	Type of IO-card

5.3 Serial I/O

Serial I/O table defines the communication in the case of serial interface connection. For this I/O list, Modbus serial line protocol details are used. For every other protocol, a new table or adjustments in the current table need to be made.

COMLINE defines the connection between two stations. COM STATION specifies if the serial line connection is redundant or single line from the automation side. Next parameter, PROTOCOL, further holds the specifics for the communication and few examples include Modbus RTU [6] and Modbus TCP/IP [7]. In addition, under PORT field, the following is specified:

1. Baud rate
2. Start bit
3. Stop bit
4. Parity

While the previous fields are common for each signal in that serial line, the rest of the information in this table is more signal specific. FUNCTIONCODE determines the range where the register is allocated and if the information is read from or written to the register. Parameters ADDRESS and DATA TYPE define the register must be specified. BIT number is only for binary signals and when a 16-bit register is used (function codes 3,4,6 and 16).

In analog signals, DATA MIN and DATA MAX represent the lowest and highest reading possible. In addition, DATA SCALE is used to represent data more accurately while multip0lying the value in the register with a fixed variable on both sides alike.

Modbus is not the only serial communication protocol used in automation systems; However, it is the most common one. Alternatively, NMEA standard data formats are often used for devices like GPS [8] and voyage data recorder (VDR) [9].

NMEA MESSAGE parameter defines the NMEA message structure. The NMEA message structure sentence includes comma separated message header, values and checksum. For values with one or more decimals, a dot (“.”) is used instead of a comma. VPW, Speed - Measured parallel to wind message standard looks like this [2]:

VPW,x.x,N,x.x,M*hh<CR><LF>

NMEA SPECIFICATION parameter specifies the field number with a description. The number indicates the location of the comma, after which the value is stored. The available values used for VPW message structure include:

1. Speed, "-" means downwind, knots
2. N = Knots
3. Speed, "-" means downwind, m/s
4. M = Meters per second

Table 8: Standardized serial I/O subgroup

FIELD	**CATEGORY**	**DESCRIPTION**
TAG	ALL	Signal ID, in form of "SYSTEM"."EQUIPMENT"."ITEM"
COMLINE	SERIAL-IO	Serial line identifier where the signal is connected to (serial line signals only)
COM STATION	SERIAL-IO	PAC A or B (or A+B in case of redundant serial line) where the serial line is connected to (serial line signals only)
PROTOCOL	SERIAL-IO	Serial line protocol type
FUNCTIONCODE	SERIAL-IO	MODBUS function code (MODBUS signals only)
PORT	SERIAL-IO	Serial line port and communication parameters (IP address, TCP port for TCP/IP connection and COM-port, baud rate, bits, parity and stop bits for RS422/RS485 [10])
ADDRESS	SERIAL-IO	MODBUS register/bit (MODBUS signals only)

BIT	SERIAL-IO	Bit within MODBUS address (bit coded MODBUS signals only)
DATA TYPE	SERIAL-IO	Serial line data type - INT/UINT/BOOL/REAL (MODBUS signals only)
DATA MIN	SERIAL-IO	Serial line analog signal minimal value (analog MODBUS signals only)
DATA MAX	SERIAL-IO	Serial line analog signal maximal value (analog MODBUS signals only)
DATA SCALE	SERIAL-IO	Serial line analog signal scaling factor (gain/multiplier to get decimals from real value) (analog MODBUS signals only)
NMEA MESSAGE	SERIAL-IO	NMEA message structure, that includes one or more values
NMEA SPECIFICATION	SERIAL-IO	Specifies the field number where the signal value is located.

5.4 Signal

SIGNAL NAME gives information to the automation operator about the equipment and can have a character limit due to being used in automation systems (for example 30 characters). SIGNAL FUNCTION specifies the meaning of a signal, whether it be an input and output and is only used for binary inputs or outputs. SIGNAL DESCRIPTION column is used to specify any additional information regarding the functionality of the signal.

SIGNAL TYPE specifies if the signal is hard-wired or transmitted over a serial line communication. In case of serial line signals, the value will always be ‘SL’. However, for hard-wired signals, the value can be one of the following:

- ‘BI’- Binary Input
- ‘BO’- Binary Output
- ‘AI’- Analog Input
- ‘AO’- Analog Output

All signals containing ‘SL’ as SIGNAL TYPE will have specification under serial I/O table filled out. For the other values, parameters under the hard-wired I/O table must be filled out.

SIGNAL CODE and MANUF TAG are fields indicating any supplier side details. SIGNAL MIN and Signal Max fields define the analog signal upper and lower range. SIGNAL UNIT is required to specify the reading of an analog unit. Lastly, I/O TYPE is used to specify the sensor type.

Table 9: Standardized serial I/O subgroup

FIELD	CATEGORY	DESCRIPTION
TAG	ALL	Signal ID, in form of "SYSTEM"."EQUIPMENT"."ITEM"
SIGNAL	SIGNAL	Signal ID, in form of "SYSTEM""EQUIPMENT""ITEM"
SIGNAL NAME	SIGNAL	TAG NAME + ISA (limited)
SIGNAL FUNCTION	SIGNAL	Signal function description
SIGNAL DESCRIPTION	SIGNAL	TAG NAME + ISA, not used by IAS
SIGNAL CODE	SIGNAL	Yard defined signal type, not used by IAS
SIGNAL TYPE	SIGNAL	Sensor type together with interface type
SIGNAL MIN	SIGNAL	Analog signal range - Minimal value (sensor scaling)
SIGNAL MAX	SIGNAL	Analog signal range - Maximal value (sensor scaling)
SIGNAL UNIT	SIGNAL	Analog signal unit (sensor/input signal scaling)
I/O TYPE	SIGNAL	Specific Sensor type together with interface type
MANUF TAG	SIGNAL	Sensor supplier signal identifier, not used by IAS

5.5 Cable

All signals have cable related details that are mandatory. For hard-wired signals, all fields must be filled out. In case all attributes for hardwired signals under cable are an exact match with another signal, DBMS recognizes this as an error and adds it to the error report. For serial line signals, this is ignored as more than one signal will be transferred, but the information regarding cable cannot be null. The DBMS separates between signal types based on the Signal type column under the signal table.

All cable related signals are related to cable information and are most important for cable connectors and electricians. CONNECTION ID specifies how to connect the cable between both systems or sensors and the system. CABLE NO and CABLE TYPE are used to specify cable in order to manage cabling connected between systems in the instrument list. LOOP TO, LOOP FROM and CABLE PAIR are required to set up electrical instalments.

Table 10: Standardized cable subgroup

FIELD	CATEGORY	DESCRIPTION
TAG	ALL	Signal ID, in form of "SYSTEM"."EQUIPMENT"."ITEM"
CONNECTION ID	CABLE	not used by IAS
CABLE NO	CABLE	Cable number, not used by IAS
CABLE TYPE	CABLE	Cable type, not used by IAS
CABLE PAIR	CABLE	Cable pair/core, not used by IAS
LOOP TO	CABLE	Location where Cable is connected on IAS side, not used by IAS
LOOP FROM	CABLE	Location where Cable is connected on the other (sensor) side, not used by IAS

5.6 General

General table will include revisional details and a NOTE field, for additional comments from the automation coordinator. Revisional details include REV, that serves as revisional control number and REV SIGN, where the name initials of the last person to edit the signal.

REV STATUS specifies the status of the last edit, for example modified, added or deleted, and REV NOTE is used to mention any additional information, like “Deleted signal replaced with signal x”. Lastly, REV DATE specifies the date of the last time signal was edited.

Table 11: Standardized general subgroup

FIELD	CATEGORY	DESCRIPTION
TAG	ALL	Signal ID, in form of "SYSTEM"."EQUIPMENT"."ITEM"
NOTE	GENERAL	Note/additional info, not used by IAS
REV	GENERAL	Revision control - revision number, not used by IAS
REV SIGN	GENERAL	Revision control - initials on signed person, not used by IAS.
REV STATUS	GENERAL	Revision control - signal status, not used by IAS
REV NOTE	GENERAL	Revision control - note/additional info, not used by IAS
REV DATE	GENERAL	Revision control - revision date, not used by IAS

6 Conceptual model of database management system

A database management system (DBMS) is a software package designed to define, manipulate, retrieve and manage data in a database [11].The main purposes of the designed database in this thesis are help manage the database, generates automation configuration files, mimics, drawings and reports.

Conceptual data model maps the concepts and their relationships of the database management system. For overview of the system design purposes, Enterprise Architect version 12 is used. Enterprise Architect is a modelling platform for designing and constructing software systems[12].Each of these subcategories mentioned in paragraph five have a separate table in the database management system. TAG is a unique identifier that is assigned on every signal in the I/O list and it acts as a primary key for all tables in the DBMS.

All the information is imported from the I/O list into one database. That data will be divided between multiple classes in the database management tool. After manually editing the data, updating project-based commands, checking results, export files for automation system configuration, standard testing mimics, drawings, reports and other project-based documentation is created. This process is illustrated on figure 3.

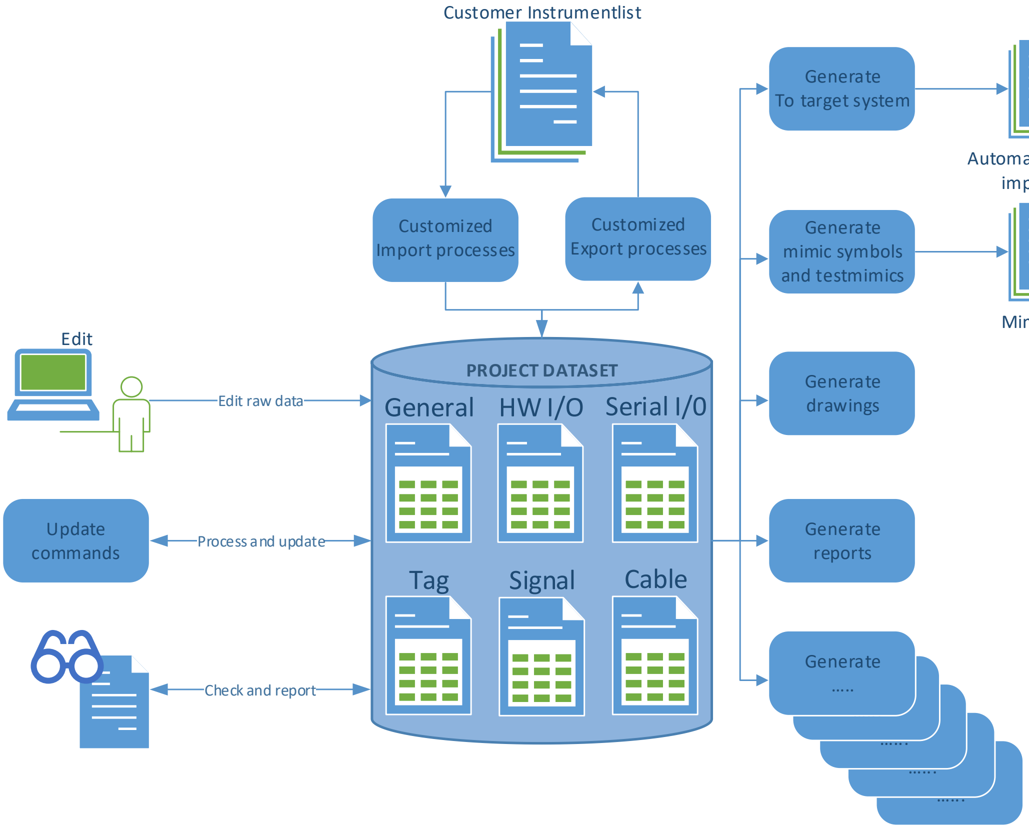

Figure 3: How I/O list is used by DBMS

6.1 Overview of DBMS

The overview of the DBMS is a map of concepts and their relationships and it is illustrated on Figure 4: The part of business architecture that the project covers in detail. Contents of the diagram are described under the paragraphs 6.2, 6.3 and 6.4.

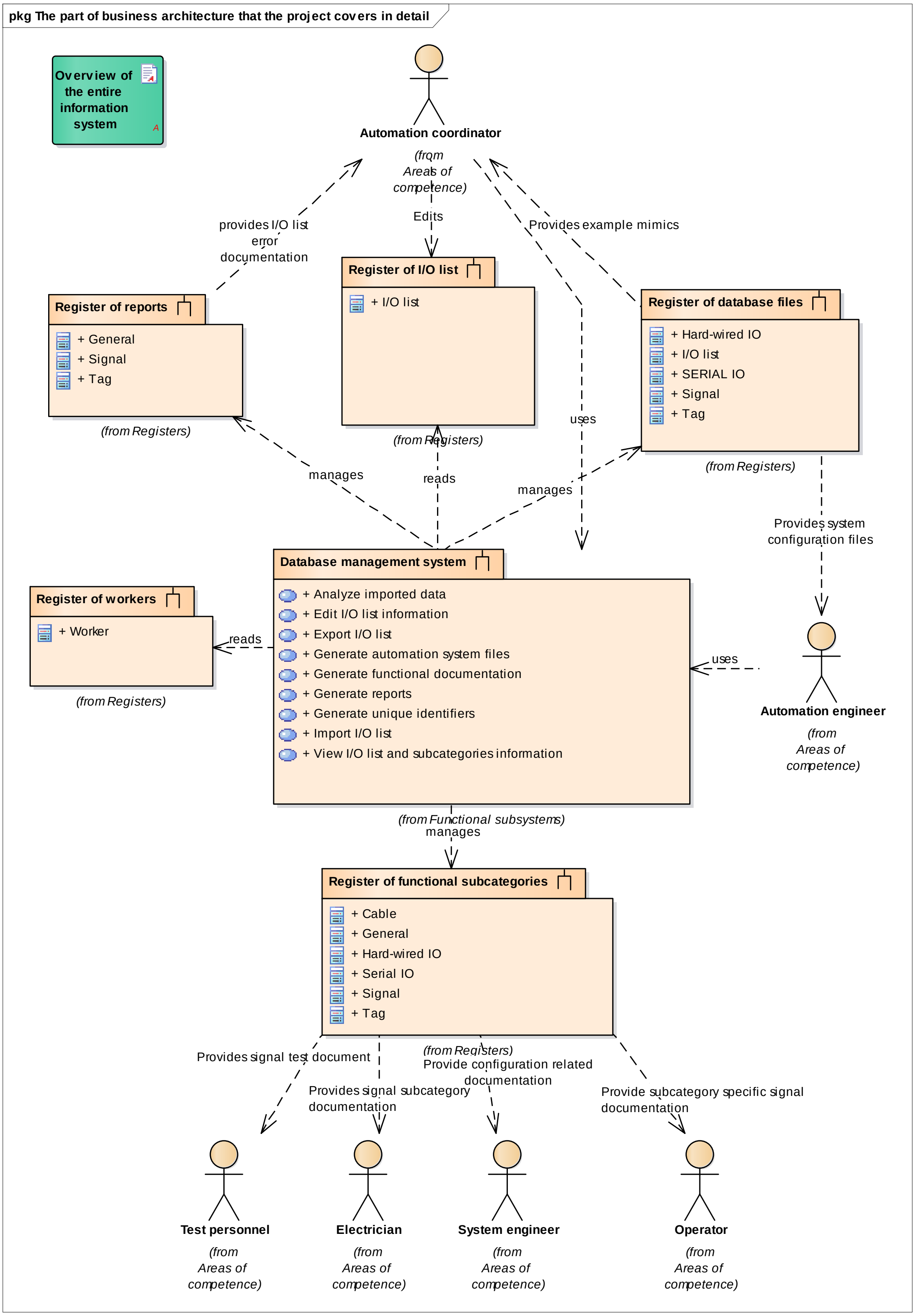

Figure 4: The part of business architecture that the project covers in detail

6.2 Actors

An actor is someone who modifies or receives data from the information system. There is a one-to-one correlation between the I/O list users mentioned in chapter three and the actors for the DBMS.

Table 12: Overview of different actor types in the database.

ACTOR_CODE	ACTOR_NAME	ACTOR_DESCRIPTION
1	Automation engineer	Responsible for the DBMS and the configuration of automation system
2	Automation coordinator	Responsible for the I/O list as a whole and updates the values
3	System engineer	Verifies that the external configuration to automation system is configured according to I/O list
4	Electrician	Responsible for the everything related to installing and connecting the cable
5	Test personnel	Test personnel are responsible for testing the connection, functionality and monitoring of systems.
6	Operator	Operator is a person who monitors and controls multiple systems with the help of automation systems.

The database updates parameters in the I/O list class general (see more info under paragraph 5). Parameters REV, REV SIGN and REV DATE are renewed when automation coordinator edits or imports I/O list.

These updates include setting the REV_DATE time to time right now, replacing the REV_SIGN with the PERSONAL_CODE of the database user and setting the REV code to the current revision. These parameters are only updated when any parameter under the Tag, Signal, Cable, Hard-wired I/O or serial I/O has been modified.

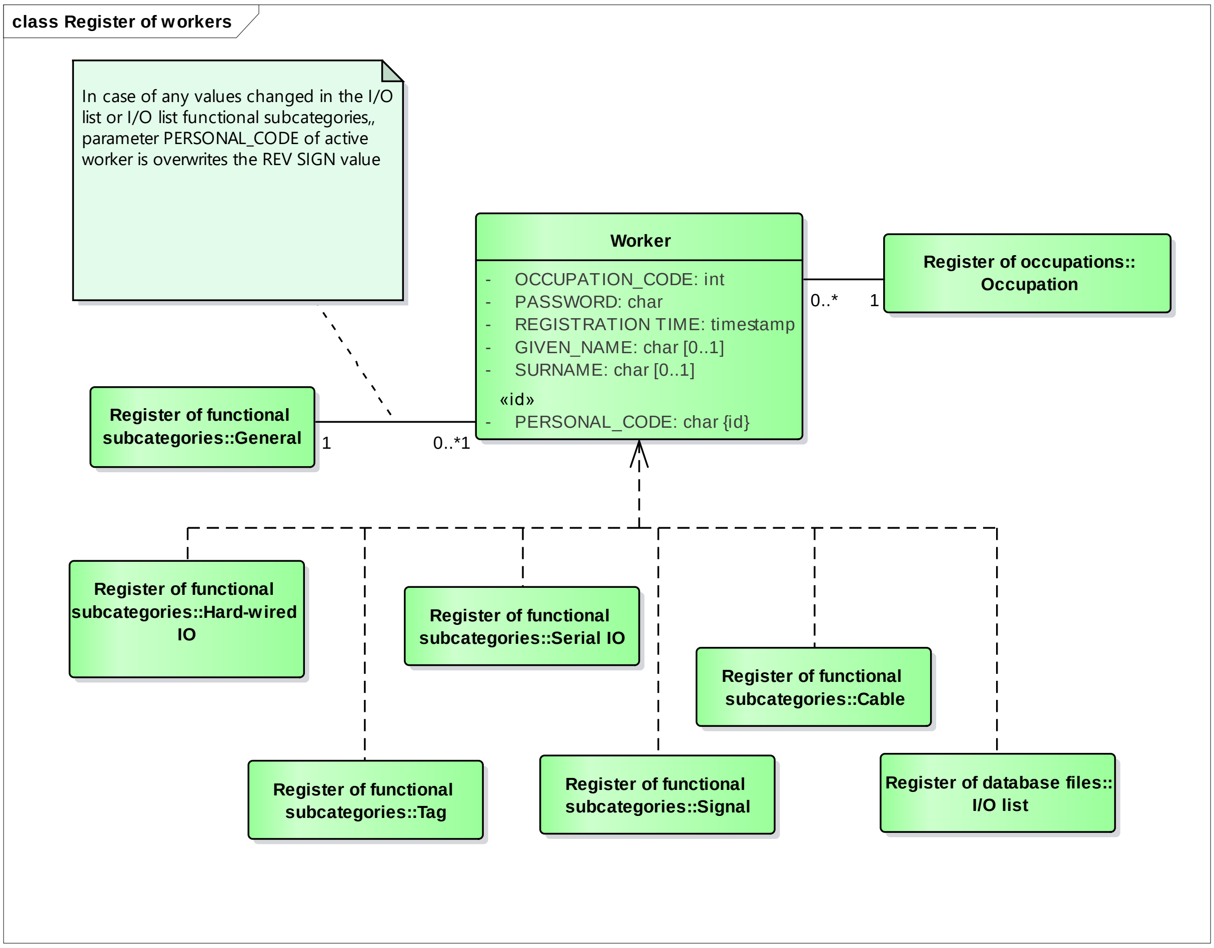

Figure 5: Class diagram register of workers

6.3 I/O list database functions

Each actor classifier defines the functional rights. For test personnel, operator, electrician and subsystem engineer viewing I/O list and subcategories information is the only function allowed.

Automation coordinator is the only user allowed to edit I/O list information directly in the database, as well as the only one allowed to export the I/O list from the database. All database edits after the export of the I/O list, will include a new revision code.

The automation coordinator and the automation engineer can use function analyse imported data, in case the I/O list changes were handled outside of the database. Analyse imported data activates a query which returns a list of logical errors made in the I/O list.

Generate reports is used by the automation coordinator and the automation engineer to automatically create automation specific information. One example of such report is an overview of number of signals used and available in each signal station. This information from overview could be used to plan for an additional connection.

Both the automation coordinator and the automation engineer can import the I/O list into the database management system. Importing will replace the existing I/O list with the new one. The main difference of editing information in the database and externally, is how revisional data will be handled.

In case of editing externally, the revisional data must be updated manually by the automation coordinator. This means the revision columns have to be updated manually before importing the new revision. When the I/O list is edited from the database, the DBMS fills in REV_DATE, REV_DATE and REV parameters.

By generating database system files, the query will export configuration files for the automation system. In order to prepare all configuration files, the automation engineer must define system specific identifiers, like the program template.

Generating functional documentation is also only available only for the automation engineer. Functional documentation includes different templates such as an overview of serial interfaces to external systems. The use cases mentioned are included in use case diagram on next page.

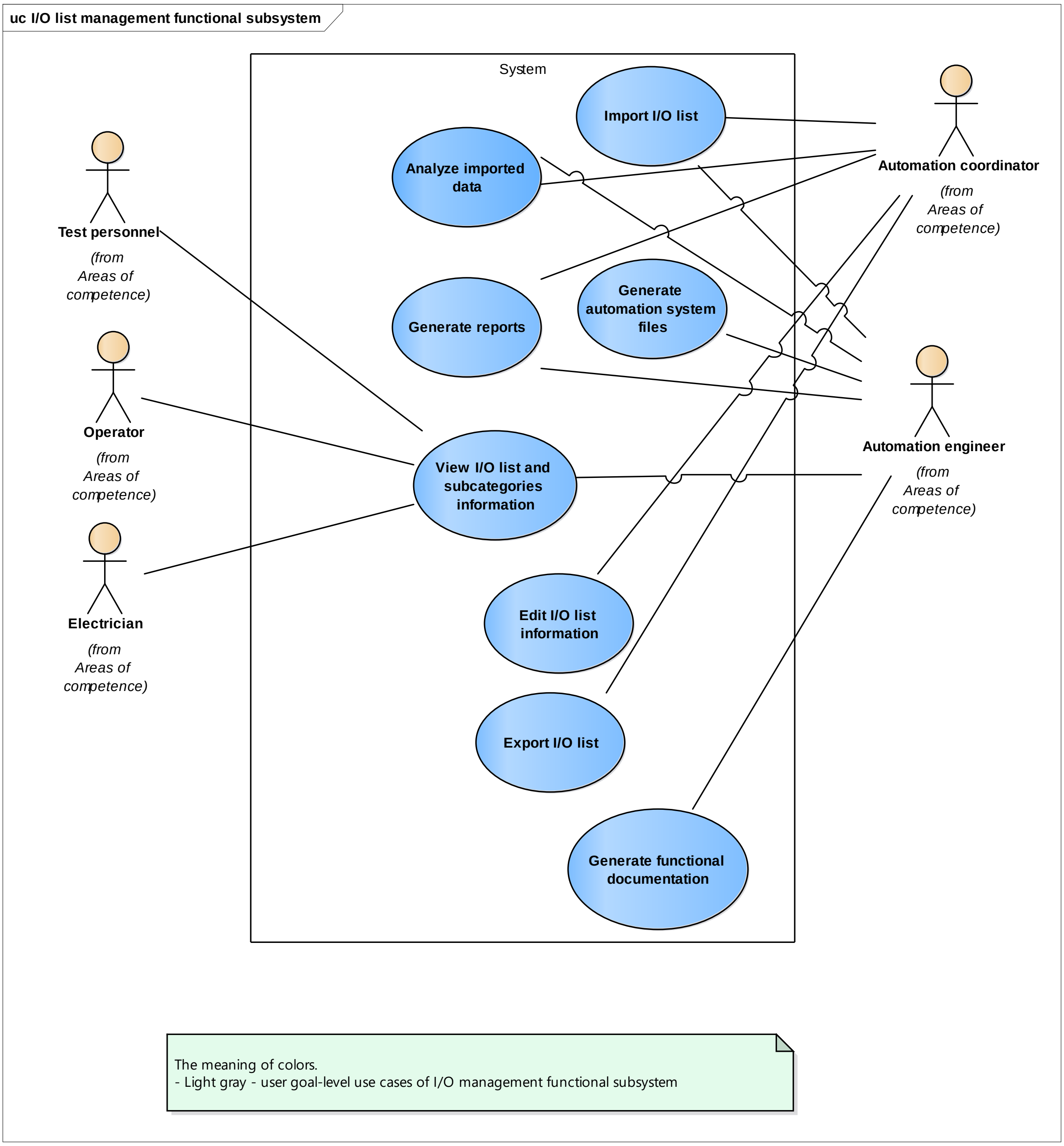

Figure 6: Use case diagram of I/O list management

6.4 Main entity types

The information system manages data about entities and allows data from several entities to all be related together into one whole. The main entity types for information system include:

- Tag
- Hard-wired I/O

- Serial I/O
- Signal
- Cable
- General
- Worker
- Organization
- Functional subcategory
- Administrative document
- I/O list
- Work schedule

6.5 Functional subsystems and registers

Functional subsystems and registers correspond to the main activities of the organization. and are defined in Table 13: Overview of functional subsystems types in the database.

Table 13: Overview of functional subsystems

Functional subsystem	**Register that is managed by the functional subsystem**
Tag management functional subsystem	Register of tags
Signal management functional subsystem	Register of signals
Cable management functional subsystem	Register of cables
Functional documentation management functional subcategories	Register of functional subcategories
I/O list functional subsystem	Register of I/O list
Serial I/O functional subsystem	Register of serial I/O-s
Hard-wired I/O management functional subsystem	Register of hard-wired I/O-s

Administrative functional subsystems and registries can be used by many different organizations that perform different activities and have different goals. Administrative functions are defined in Table 14: Overview of administrative functional subsystems.

Table 14: Overview of administrative functional subsystems

Functional subsystem	**Register that is managed by the functional subsystem**
Worker management functional subsystem	Register of workers
Organization management functional subsystem	Register of organizations
Administrative document management functional subsystem	Register of administrative documents
Work schedule management functional subsystem	Register of work schedules
Working management functional subsystem	Register of workings
Worker proposal management functional subsystem	Register of worker proposals
Development work management functional	Register of development works

7 Summary

An I/O list, commonly also referred to as instrument or signal list, is a document containing a list of signals which serves as an input or output for a control and monitoring system. It describes programs, operations and data, that is being transferred between two or more systems and gives an overview of work scope.

The aim of this thesis was to provide a format that could be used as an I/O list standard. This thesis gives overview of I/O list contents, different I/O lists, the users of I/O list and their requirements, how to format the I/O list and how the model the database management system would look like.

After defining the I/O list, the thesis defines the possible users and their expectations regarding the I/O list. The main benefactor of universal I/O list format would be automation engineer, as setting up the configuration for the automation system and generating drawings would require less work.

The secondary benefactor would be the automation coordinator, as the database modelled in this thesis could give feedback related to possible mistakes in the I/O list. In addition, the database system would update revisional information if the changes are made in the database directly, opposed to making the changes externally and the importing them.

For the analysis of different I/O lists, a total of six I/O list were examined. For each I/O list parameters, missing information, common information between lists different and overall structure was inspected. The contents of three I/O lists are analysed in this thesis.

After combining the requirements different users and the number including important information from the sample I/O lists, a standardized I/O list format, was created. The standardized I/O list contains 82 parameters, all of which were separated into 6 subcategories. Each of subcategories is meant for one or more I/O list user types. The subcategories were created to make the I/O list more comprehendible.

In the final chapters, the conceptual data model of database management system was made. Overview of actors, database functions, main entity types, functional subsystems and registers was presented.

The future work for this thesis involves finishing developing the database system, integration with other products, testing the I/O list for different projects and making corrections where necessary.

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● Appendix 1 – Links to various project I/O lists

Project A IO list format example:

https://drive.google.com/open?id=1q2uX7PZT_rz0ybuzNp9MpuupjxZ1y1Ad

Project B IO list format example:

https://drive.google.com/open?id=1dREnNvhUg7iLh72mW6nA1_ilEeBzzOj-

Project C IO list format example:

https://drive.google.com/open?id=11l-55QJuT4NyUTfdBkifjS1_rOvoEiw8

Project D IO list format example:

https://drive.google.com/open?id=1Byj7mdVfCldAYyRgOgRbGheWfc8c4evs

Project E IO list format example:

https://drive.google.com/open?id=1XHUUkt4Qwxrz7VUBFZlsq-7W1KBuu3_4

Project F IO list format example:

https://drive.google.com/file/d/19tqyC2VUaMa5Y3Y-
eGAATCbDv9XzSD_o/view?usp=sharing

- # Appendix 2 – Standardized I/O list example data and content overview

Standardized I/O list format example:

https://drive.google.com/file/d/1xq2zeRxRGUiR8f86AlBp33tSZi3zPKNh/view?usp=sharing

Table 15: Standardized I/O list example data

REC	5121001	6311021	6222027
SYSTEM	5121	6111	6222
EQUIPMENT	X015	011	011
ITEM	1	1	2
TAG	5121X015.1	6311.011.1	6311.011.2
TAG NAME	FO STORAGE TANK OVERFLOW	LO TRANSFER PUMP1	LO TRANSFER PUMP1
TAG FUNCTION	RUNNING	REMOTE	START
TAG DESCRIPTION	FO STORAGE TANK OVERFLOW	LO TRANSFER PUMP1	LO TRANSFER PUMP1
TAG MIN	0		
TAG MAX	1200		
TAG UNIT	rpm		
TAG DECIMAL	0		
LOW LIMIT LL			
LOW LIMIT L			
HIGH LIMIT H	1000		
HIGH LIMIT HH			
DELAY LL			
DELAY L			
DELAY H	1		
DELAY HH			
DELAY			

PRIORITY LL			
PRIORITY L			
PRIORITY H			
PRIORITY HH			
PRIORITY LL		5	
SIGNAL	51210011	63110211	62220271
SIGNAL NAME	FO STORAGE TANK OVERFLOW	LO TRANSFER PUMP1	LO TRANSFER PUMP1
SIGNAL FUNCTION	RUNNING	REMOTE	START
SIGNAL DESCRIPTION	FO STORAGE TANK OVERFLOW	LO TRANSFER PUMP1	LO TRANSFER PUMP1
SIGNAL CODE	60	60	40
SIGNAL TYPE	SLAI	SLDI	DO
SIGNAL MIN	0		
SIGNAL MAX	1200		
SIGNAL UNIT	rpm		
I/O TYPE	MBAI	MBBIT	NO
EQUIPMENT ID	6111.110	6111.110	6222.PFC1
CONNECTION ID			
MANUF TAG			
CABLE NO			
CABLE TYPE			
CABLE PAIR			
LOOP TO			
LOOP FROM			
CABINET	9311AS07	9311AS07	9311AS07
SIGNAL STATION	PAC11	PAC11	PAC03
RACK			1
CARD			5
CH			8

TERMINAL 1			X2:10 NO
TERMINAL 2			X2:11 COM
TERMINAL 3			
TERMINAL 4			
CARD TYPE			340
COMLINE	ME1COM	ME1COM	
COM STATION	A+B	A+B	
PROTOCOL	MODBUS MASTER	MODBUS MASTER	
FUNCTIONCODE	6	6	
PORT	192.168.99.99:502	COM4:19200,8,N,2	
ADDRESS	41219	41220	
BIT		6	
DATA TYPE	INT	BOOL	
DATA MIN	0		
DATA MAX	1200		
DATA SCALE	1		
DOCUMENT			
NMEA MESSAGE			
NMEA SPECIFICATION			
MAIN SYSTEM	ME	ME	PROPULSION
SYSTEM	ME1	ME1	PFC1
DWG			
SIGNAL AREA NR	5013	5013	5018
MACH GROUP	MACHINERY	MACHINERY	PEMS
ALARM GROUP	ENGINES	ENGINES	PROP & THR
VDR MESSAGE			
E0 ALARM			
SENSOR TYPE			
SENSOR MAKER			
NOTE			
REV	B	A	F

REV SIGN	JTE	JTE	JTE
REV STATUS	TESTED	IMPLEMENTED	IN PROGRESS
REV NOTE			
REV DATE	1/16/2015	1/16/2015	1/16/2015

Table 16: Standardized I/O list content overview

FIELD	**CATEGORY**	**DESCRIPTION**
REC	TAG	Yard internal signal ID (if needed), not used by IAS
SYSTEM	TAG	Subsystem identifier where the signal belongs to
EQUIPMENT	TAG	Equipment identifier where the signal belongs to
ITEM	TAG	Signal number under the equipment
TAG	TAG	Signal ID, in form of "SYSTEM"."EQUIPMENT"."ITEM"
TAG NAME	TAG	Signal description/Equipment description (limited)
TAG FUNCTION	TAG	Instrument code/Description of signal Function
TAG DESCRIPTION	TAG	Signal description/Equipment description, not used by IAS
TAG MIN	TAG	Analog display range - Minimal value (presented on the operator stations)
TAG MAX	TAG	Analog display range - Maximal value (presented on the operator stations)
TAG UNIT	TAG	Analog display unit (presented on the operator station)
TAG DECIMAL	TAG	Analog display precision - No. of decimals (presented on the operator station)
LOW LIMIT LL	TAG	Analog display alarm limits - Low Low alarm
LOW LIMIT L	TAG	Analog display alarm limits - Low alarm
HIGH LIMIT H	TAG	Analog display alarm limits - High alarm
HIGH LIMIT HH	TAG	Analog display alarm limits - High High alarm
DELAY LL	TAG	Analog display alarm delays - Low Low alarm
DELAY L	TAG	Analog display alarm delays - Low alarm
DELAY H	TAG	Analog display alarm delays - High alarm
DELAY HH	TAG	Analog display alarm delays - High High alarm
DELAY	TAG	Binary display alarm delay
PRIORITY LL	TAG	Analog display alarm priorities - Low Low alarm (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)

PRIORITY L	TAG	Analog display alarm priorities - Low alarm (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)
PRIORITY H	TAG	Analog display alarm priorities - High alarm (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)
PRIORITY HH	TAG	Analog display alarm priorities - High High alarm (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)
PRIORITY	TAG	Binary display alarm priority (1=critical, 2=not critical, 3=warning, 4=message, 5=event/not alarm)
SIGNAL	SIGNAL	Signal ID, in form of "SYSTEM""EQUIPMENT""ITEM"
SIGNAL NAME	SIGNAL	TAG NAME + ISA (limited)
SIGNAL FUNCTION	SIGNAL	Signal function description
SIGNAL DESCRIPTION	SIGNAL	TAG NAME + ISA, not used by IAS
SIGNAL CODE	SIGNAL	Yard defined signal type, not used by IAS
SIGNAL TYPE	SIGNAL	Sensor type together with interface type
SIGNAL MIN	SIGNAL	Analog signal range - Minimal value (sensor/input signal scaling)
SIGNAL MAX	SIGNAL	Analog signal range - Maximal value (sensor/input signal scaling)
SIGNAL UNIT	SIGNAL	Analog signal unit (sensor/input signal scaling)
I/O TYPE	SIGNAL	Specific Sensor type together with interface type
EQUIPMENT ID	TAG	Equipment ID, in form of SYSTEM.EQUIPMENT
CONNECTION ID	CABLE	not used by IAS
MANUF TAG	SIGNAL	Sensor supplier signal identifier, not used by IAS
CABLE NO	CABLE	Cable number, not used by IAS
CABLE TYPE	CABLE	Cable type, not used by IAS
CABLE PAIR	CABLE	Cable pair/core, not used by IAS
LOOP TO	CABLE	Location where Cable is connected on IAS side, not used by IAS
LOOP FROM	CABLE	Location where Cable is connected on the other (sensor) side, not used by IAS
CABINET	HW-IO	Cabinet where the signal is connected to on IAS side
SIGNAL STATION	HW-IO	PAC where the signal is connected to
RACK	HW-IO	IO-rack number where the signal is connected to (hardwired signals only)

CARD	HW-IO	IO-card number where the signal is connected to (hardwired signals only)
CH	HW-IO	IO-channel number where the signal is connected to (hardwired signals only)
TERMINAL 1	HW-IO	IO-channel Terminal 1
TERMINAL 2	HW-IO	IO-channel Terminal 2
TERMINAL 3	HW-IO	IO-channel Terminal 3
TERMINAL 4	HW-IO	IO-channel Terminal 4
CARD TYPE	HW-IO	Type of IO-card (hardwired signals only)
COMLINE	SERIAL-IO	Serial line identifier where the signal is connected to (serial line signals only)
COM STATION	SERIAL-IO	PAC A or B (or A+B in case of redundant serial line) where the serial line is connected to (serial line signals only)
PROTOCOL	SERIAL-IO	Serial line protocol type
FUNCTIONCODE	SERIAL-IO	MODBUS function code (MODBUS signals only)
PORT	SERIAL-IO	Serial line port and communication parameters (IP address, TCP port for TCP/IP connection and COM-port, baud rate, bits, parity and stop bits for RS422/RS485)
ADDRESS	SERIAL-IO	MODBUS register/bit (MODBUS signals only)
BIT	SERIAL-IO	Bit within MODBUS address (bit coded MODBUS signals only)
DATA TYPE	SERIAL-IO	Serial line data type - INT/UINT/BOOL/REAL (MODBUS signals only)
DATA MIN	SERIAL-IO	Serial line analog signal minimal value (analog MODBUS signals only)
DATA MAX	SERIAL-IO	Serial line analog signal maximal value (analog MODBUS signals only)
DATA SCALE	SERIAL-IO	Serial line analog signal scaling factor (gain/multiplier to get decimals from real value) (analog MODBUS signals only)
NMEA MESSAGE	SERIAL-IO	NMEA message structure, that includes one or more values
NMEA SPECIFICATION	SERIAL-IO	Specifies the field number where the signal value is located.
DOCUMENT	GENERAL	Document for specification of functionality, not used by IAS
MAIN SYSTEM NAME	GENERAL	MAIN SYSTEM in text format, not used by IAS
SYSTEM NAME	GENERAL	SYSTEM in text format, not used by IAS

DWG	GENERAL	Referenced P&ID drawing number, not used by IAS
SIGNAL AREA NR	GENERAL	Area identifier where sensor is located, not used by IAS
MACH GROUP	TAG	Machinery group (separation in order to transfer control for specific part of system to different control location)
ALARM GROUP	TAG	Alarm group (E0 and non-E0 signals must be separated into different alarm groups)
VDR MESSAGE	TAG	VDR signal identifier (format to clarified based on VDR solution), selection of mandatory or not mandatory VDR signal
E0 ALARM	TAG	Alarm used during E0
SENSOR TYPE	SIGNAL	Sensor type - model number, not used by IAS
SENSOR MAKER	SIGNAL	Sensor type - maker name, not used by IAS
NOTE	GENERAL	Note/additional info, not used by IAS
REV	GENERAL	Revision control - revision number, not used by IAS
REV SIGN	GENERAL	Revision control - initials on signed person, not used by IAS
REV STATUS	GENERAL	Revision control - signal status, not used by IAS
REV NOTE	GENERAL	Revision control - note/additional info, not used by IAS
REV DATE	GENERAL	Revision control - revision date, not used by IAS