AGILE

rApidly-deployable, self-tuninG, self-reconfIgurabLE nearly-optimal control design for large-scale nonlinear systems

257806, FP7-ICT-2009-3.5

Deliverable D4.1.0:

Interfacing AGILE System with SCADA/DCSs – first version

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Deliverable Summary Sheet

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Deliverable D4.1.0: Short Description

The purpose of this Deliverable is to report on the work performed within Y1 of AGILE as far as it concerns Tasks 4.1 and 4.2 of WP4 of the project. This Deliverable will serve as the basis for the completion of Tasks T4.1 and T4.2 which will result in the detailed specification and the development of all the building blocks and software modules that are required for interfacing the integrated AGILE system with existing open-architecture SCADA/DCSs. With respect to the above Tasks, the work performed within Y1 of the project (and is reported in this Deliverable) is as follows:

1. An extensive and thorough overview of the characteristics as well as capabilities and limitations of existing or planned open-architecture SCADA, DCS and industrial large-scale control systems. (Task 4.1 SCADA/DCS Requirements and M9: Identification of SCADA/DCS Requirements), i.e.,
    a. The functional requirements for interfacing the integrated AGILE system with SCADA/DCSs;
    b. Types of performance requirements, constraints, rules, settings and supervisory commands imposed at the SCADA/DCS level in existing SCADA/DCSs.
    c. Types of performance requirements and constraints – which AGILE can efficiently and automatically address but – the existing LSCS designs embedded in SCADA/DCSs are not able to automatically or efficiently handle;

    It is worth noticing that – including the SCADA/DCS application areas involved in the 2 AGILE test cases – a total of 5 different SCADA/DCS application areas have been used for the overview mentioned above. The external user group of AGILE (Milestone 3) has been used towards such a purpose.

2. The approach to be adopted within the AGILE system for transforming performance requirements, constraints, rules, settings and supervisory commands imposed at the SCADA/DCS level in existing SCADA/DCSs. According to the AGILE LSCS developments (WP2 and WP3), any of the aforementioned requirements, constraints, rules, etc can be managed by AGILE provided they are transformed in algebraic constraints as there is a need to convert control requirements expressed in linguistic form to algebraic (functional) constraints. As an example, the many rules extracted from the large office building in Kassel (see ANNEX 1 and ANNEX 2) are transformed in functional constraints.
3. Finally, and based on the results of steps 2 and 3 above, the Graphical User Interfaces (GUI) to be developed for the AGILE 2 Test Cases are described.

In the last chapter of the Deliverable, there are indicated which External User Group are involved in AGILE (Milestone 3). Also for support reasons there are two annexes. The first one, it is described the total control of the building in Kassel divided in two different categories, the controls belonging to the single zones (individual/room controls) and those that are implemented over systems that control the complete building (general variables). It is remarkable that is based on PEBBLE project, which is a leading project (funded by FP7) to measure and control the smart building. The second one describes the process of opening window algorithm (corresponding to the second test case), written in MATLAB that perform the Converting linguistic rules to optimization Constraints.

Keywords: convex control desisn, open-architecture SCADA/DCS

Deliverable D4.1.0: Revision History

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Executive Summary

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4. An extensive and thorough overview of the characteristics as well as capabilities and limitations of existing or planned open-architecture SCADA, DCS and industrial large-scale control systems. (**Task 4.1 SCADA/DCS Requirements and M9: Identification of SCADA/DCS Requirements**), i.e.,

    a. The functional requirements for interfacing the integrated AGILE system with SCADA/DCSs;

    b. Types of performance requirements, constraints, rules, settings and supervisory commands imposed at the SCADA/DCS level in existing SCADA/DCSs.

    c. Types of performance requirements and constraints – which AGILE can efficiently and automatically address but – the existing LSCS designs embedded in SCADA/DCSs are not able to automatically or efficiently handle;

   It is worth noticing that – including the SCADA/DCS application areas involved in the 2 AGILE test cases – a total of 5 different SCADA/DCS application areas have been used for the overview mentioned above. The external user group of AGILE (**Milestone 3**) has been used towards such a purpose.

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the process of opening window algorithm (corresponding to the second test case), written in MATLAB that perform the Converting linguistic rules to optimization Constraints.

1 Introduction

The purpose of this Deliverable is to report on the work performed within Y1 of AGILE as far as it concerns Tasks 4.1 and 4.2 of WP4 of the project. This Deliverable will serve as the basis for the completion of Tasks T4.1 and T4.2 which will result in the detailed specification and the development of all the building blocks and software modules that are required for interfacing[1] the integrated AGILE system with existing open-architecture SCADA/DCSs. Tasks 4.1 and 4.2 are concerned with the following work:

Task 4.1 is involved with an extensive and thorough overview of the characteristics as well as capabilities and limitations of existing or planned open-architecture SCADA, DCS and industrial large-scale control systems. The purpose of this overview is to understand what needs to be done in order to embed the integrated AGILE system within today's open-architecture SCADA/DCSs. The overview and the respective identification of requirements focus on the following issues:

1. The functional requirements for interfacing the integrated AGILE system with SCADA/DCSs, i.e. requirements such as (a) the type, updating frequency and communication protocols for variables and parameters (e.g. sensor and control measurements, supervisory and overriding commands, fault flags and reports, alarms, etc) to be communicated between the two (AGILE and SCADA/DCS) systems, (b) the type, updating frequency and communication protocols for variables and parameters that are to be fed from/to the AGILE system to/from the Remote Terminal Units (RTU) or Programmable Logic Controllers (PLC) through the SCADA/DCS, communication protocols, (c) which of the above-mentioned variables and parameters are to be communicated through the «client layer» and which through the «data server layer» of the SCADA/DCS, (d) which of the above-mentioned variables and parameters are to be communicated on a continuous/periodic-basis and which on publish-subscribe or event-driven basis.

2. Types of performance requirements, constraints, rules, settings and supervisory commands imposed at the SCADA/DCS level (typically through the SCADA HMI) such as hard/soft limiters, «IF-THEN logics», overriding commands imposed by the SCADA/DCS operators,
3. Types of performance requirements and constraints – which AGILE can efficiently and automatically address but – the existing LSCS designs embedded in SCADA/DCSs are not able to automatically or efficiently handle; such performance requirements and constraints include complicated Re-Use or QoS requirements, constraints involving – nonlinear - combinations of sensor measurements and, mainly, fault-recovery and re-configuration requirements, etc.

An AGILE's External User Group has been involved in this task – by means of personal interviews and questionnaires – in order to guarantee that the above mentioned requirements are identified to the fullest extent.

[1] Please note that it is not AGILE's ambition the interfaces to render the AGILE system directly interface-able to each and every of the existing SCADA/DCS but, by employing open-source principles, to make sure that the interfaces to be developed will allow the incorporation of AGILE's system in existing SCAD/DCSs at a minimum effort.

Under Task 4.2 all the necessary building blocks will be specified in detail and the respective software modules will be developed in order to

1. Render the AGILE system able to interface with existing open-architecture SCADA/DCSs, being able to receive and send all necessary data for imposing the AGILE control actions to the large-scale system controlled by the respective SCADA/DCS.
2. Extract the performance requirements, constraints and supervisory commands imposed at the SCADA/DCS HMI (typically being in the form of hard/soft limiters or "IF-THEN" logic) and translate these requirements, constraints and supervisory commands into AGILE-compatible requirements and constraints.
3. Provide the SCADA/DCS with an efficient and scalable LSCS design capable of incorporating requirements and constraints (such as complicated Re-Use or QoS requirements, constraints involving – nonlinear - combinations of sensor measurements and control inputs, controller bandwidth constraints, fault-recovery requirements, etc) that cannot be automatically or efficiently handled by LSCS designs embedded in existing SCADA/DCSs.
4. Last but not least, provide the SCADA/DCS HMI with an extra Graphical-User Interface (GUI) which will allow the designer/operator to
    a. Define performance objectives as well as requirements and constraints that cannot be automatically or efficiently handled by LSCS designs embedded in existing SCADA/DCSs.
    b. Define fault-recovery and re-configuration performance objectives and requirements.
    c. Monitor – in real-time – all the quantities necessary to assess the LSCS performance with respect to the performance objectives, requirements and constraints mentioned in a. and above.
    d. Modify (tune) parameters that are related to the above-mentioned performance objectives, requirements and constraints (e.g. the target or minimum/maximum allowable values for QoS, control bandwidth/amplitude or safety-related requirements or constraints, «trade-off» parameters controlling e.g. steady-state vs. transient performance, etc).

There will be <u>2 access levels in the above-mentioned GUI</u>: (a) in the first level – to be operated by personnel educated in the AGILE system design and use – the user enters performance objectives, requirements and constraints as *functions* of the large-scale system control and sensor measurements (by employing symbolic operations); (b) in the second level – which is to be accessed and operated by SCADA/DCS' operators – the real-time values of the aforementioned functions are provided (against their target or minimum/maximum allowable values) and the GUI user is allowed to modify parameters that affect the LSCS performance such as the target or minimum/maximum allowable values for the performance objectives, requirements and constraints imposed, "trade-off" parameters, etc. It has to be stretched out that, as AGILE's objective is not on providing "beyond-the-state-of-art" GUI's for SCADA/DCSs, simple yet standard and efficient GUI techniques will be employed for the development of the above-described GUI. Moreover, as it is not possible to embed such a GUI to each and every SCADA/DCS HMI, the GUI to be developed within this Task will act as an add-on system (with its own window) to the SCADA/DCS HMI; open-source software tools will be adopted in the development of the GUI so that it will be directly and straightforwardly implementable to any open-architecture SCADA/DCS. Finally, SCADA/DCS safety-related constraints (such as «when and how often» the operator is allowed to modify the AGILE performance-related parameters) will be incorporated in the GUI. Task 4.2 will be concluded by issuing D4.1.1 which will deliver the software interfaces along with a report detailing these interfaces.

With respect to the above Tasks, the work performed within Y1 of the project (and is reported in this Deliverable) is as follows:

7. An extensive and thorough overview of the characteristics as well as capabilities and limitations of existing or planned open-architecture SCADA, DCS and industrial large-scale control systems. (Task 4.1 SCADA/DCS Requirements), i.e.,
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2 Functional requirements for interfacing AGILE with SCADA/DCSs

In this chapter the functional requirements for interfacing the integrated AGILE system with SCADA/DCSs are described. These requirements can be classified into the following categories:

1. The type, updating frequency and communication protocols for variables and parameters (e.g. sensor and control measurements, supervisory and overriding commands, fault flags and reports, alarms, etc) to be communicated between the two (AGILE and SCADA/DCS) systems,
2. The type, updating frequency and communication protocols for variables and parameters that are to be fed from/to the AGILE system to/from the Remote Terminal Units (RTU) or Programmable Logic Controllers (PLC) through the SCADA/DCS communication protocols,
3. Which of the above-mentioned variables and parameters are to be communicated through the «client layer» and which through the «data server layer» of the SCADA/DCS,
4. Which of the above-mentioned variables and parameters are to be communicated on a continuous/periodic-basis and which on publish-subscribe or event-driven basis.

Although the implementation of the AGILE system to particular SCADA/DCS can be always adapted to meet the requirements of the specific application, below we present some general rules as far as it concerns the above-mentioned functional requirements.

1. Unless otherwise required, the AGILE system will run on a PC (or any other type of computing device) which is connected to the SCADA/DCS system. It will be receiving – either at constant sampling rate or whenever available – the **sensor measurements** through the SCADA/DCS and will return – again either at constant sampling rate or whenever requested – the **control commands** to be implemented. As the AGILE system is fully scalable and computationally simple (employing a switching logic among linear or linear-like controllers), it does not impose any special requirements on the updating frequency and communication protocols for receiving/sending the sensor measurements/control commands.
2. Despite the fact that the AGILE system can literally implement any type of **safety mechanisms** (e.g., that the control signals remain within a region), it is advisable to incorporate such mechanisms within the PLCs of the system. In such a way and no matter whether AGILE incorporate such mechanisms, the safety of the operations will be guaranteed. Please also note that the control commands as delivered by AGILE may have to be converted within the PLCs, e.g., the green times of a traffic light should have to be converted into green time durations or the opening of a blind should be converted into the application of an electric signal to the blind’s motor.
3. **Operator tuning commands** as well as **fault detection measurements** (e.g. indicating that a sensor is not working) should be conveyed to the AGILE system (via the GUI or the PLC, respectively) on an event-driven basis. As soon as the AGILE system receives these commands it will automatically perform the necessary re-designs and continue delivering the control signals. As the operation for performing the re-design is not time-consuming no special treatment of such cases is required.

3 Types of performance requirements, constraints, rules, settings and supervisory commands imposed at the SCADA/DCS level in existing SCADA/DCSs

3.1 General issues in a SCADA/DCS

In this chapter types of performance requirements, constraints, rules, settings and supervisory commands imposed at the SCADA/DCS level in existing SCADA/DCSs are described. As it is not possible to describe such performance requirements, constraints, rules, settings and supervisory commands in each and every SCADA/DCS application, we picked 5 different application areas which include the areas involved in the AGILE 2 Test Cases.

3.2 Urban traffic control

3.2.1 Input/output parameters, constraints, rules for (ADIMOT) Traffic Control System

Traffic parameters table (estimation of existing sensors):

#	Zone	Offset arterial	Junction	Remarks
1	Intensity	Intensity	Intensity	Flow rate
2	Occupancy	Occupancy	Occupancy	
3	Capacity	Capacity	Capacity	
4	Speed	Speed		Average vehicle speed

The capacity is defined by this equation:

$$\frac{\frac{I}{I_s}+\left(1-\frac{I}{I_s}\right)TO\times K}{10000}$$

Where:

I: Intensity

Is: Saturation intensity

TO: Occupancy time

K: Constant related to the occupancy time

Traffic entities are linked so that a coordination route consists of junctions and a zone is formed by coordination routes and isolated junctions not integrated into a coordination route.

Traffic parameters constraints:

Parameter	Value	Remarks
Intensity	0-Saturation intensity	
Occupancy	0-100%	
Capacity	0-100%	
Speed	~50 ppm	

All the four parameters are connected among them.

3.2.2 Parameter's dependable table for urban traffic:

Parameter	Cycle	Offset	Incident	Queue
Intensity	+/-	+/-	-	-
Occupancy	+/-	+/-	+	+/-
Capacity	+/-	+/-	+	+/-
Speed	+/-	+/-	-	+/-

A cycle length can only be applied to all the junctions in a zone. To maintain coordination between the various junctions of a zone, they must have the same cycle length or at a multiple of the cycle length with pre-determinates offset and coordination points (main stages or start stage). Main stage or start stage is usually the stage where the main street along an arterial has right of way.

The capacity parameter is the most important in the traffic study since this parameter is calculated as a ratio between the intensity and occupation. The purpose of a traffic system is to use the resources in an optimal way. To reach this objective, the system tries to keep capacity close to 90% (the value of this parameter can be changed depending on the characteristics of the city). To set this parameter, changes are made in the green time assigned to every traffic lights and in the in the cycle of the zone to control.

If capacity exceeds its optimal value, the cycle will be increased, if capacity is very low from its optimum, the cycle will be reduced.

The fact that it's detected a lack of correlation between the intensity of a subzone and its adjacent subzones may mean that an incident has occurred. In this case, it would be necessary to define the actions to take for resolution.

A high capacity on a coordination route may be caused by a queue, in which case the system must change the offsets of the junctions of the coordination route to solve the problem.

If the capacity parameter remains close to its optimum value, proceedings are not undertaken on the operation of the system.

In a more general sense and focus on how TUC works:

The main strategies to get an “optimal” network-wide signal control settings are:

- Split Control

  Split the “effective” green time to the relative phases for every signalized intersection

- Cycle Control

  Calculate the “optimal” duration of the control cycle for the network (or sub-networks)

- Offset Control

Calculate the offsets between sequential junctions of an arterial in order to enable coordination (“green wave”)

The strategy is normally summed up in fixed pre-defined network signal plans (each with different cycle times, splits, offset).

With this signal control settings we try to:

- Minimize system total delays
- Increase the capacity of the system
- Reduce the queues of the network
- Balance the queues of the network in order to avoid spillovers and gridlocks

There is the possibility to use a local strategy for a junction but it is not interesting to fulfill the objective of AGILE (anycase, traffic-actuated logic is partially used).

3.2.3 Input traffic parameters

Firstly, it will be defined the principle variables of the system, see the notation below:

State vector (in the urban traffic scenario will be occupancy/flow of the traffic network links). The real-time communication (expressed in the state vector) between junction controllers and the central computer will be updated once every cycle for simplicity and to avoid communication errors:

x=(o_1, f_1, o_2, f_2, …, o_n, f_n)

Control input vector (in the urban traffic scenario will be the green times of all the stages of all the junctions):

u=(g_{1,1},…,g_{1,p1}, g_{2,1},…, g_{2,p2},…,g_{j,1},…, g_{j, pj},…, g_{m,1},…, g_{m, pm})

To clarify this vector, here it is an example. Let (network with junctions J and number of stages F_j for each junction j)

(a) J = {1, 2, 3} (a network with |J| = 3 signal-controlled junctions, in general if A is a set of elements then |A| is the number (count) of elements of set x)

(b) F_j = {2, 5, 4}, i.e. the 1st junction has 2 stages (F_1=2), the 2nd junction has 5 stages (F_2=5), the 3rd junction has 4 stages (F_3=4)

(c) green times

(1) for the 1st junction: $g_{1,1}$, $g_{1,2}$

(2) for the 2nd junction: $g_{2,1}$, $g_{2,2}$, $g_{2,3}$, $g_{2,4}$, $g_{2,5}$

(3) for the 3rd junction: $g_{3,1}$, $g_{3,2}$, $g_{3,3}$, $g_{3,4}$

then the vector u with dimension m_u) is as follows u = ($g_{1,1}$, $g_{1,2}$,

$g_{2,1}$, $g_{2,2}$, $g_{2,3}$, $g_{2,4}$, $g_{2,5}$,

$g_{3,1}$, $g_{3,2}$, $g_{3,3}$, $g_{3,4}$) (dimension m_u) where m_u = sum of F_j = F_1 + F_2 + F_3 = 2 + 5+4 = 11 elements

Exogenous signals affecting the system (vector of numbers of vehicles entering the network origins)

w=(q_1,…,q_{25})

Here it can be also included the demand flows for specific internal links (e.g. links next to taxi plazas or parking garages) or disturbances due to accidents or public works, etc

NOTATION:

n: dimension of the traffic network links

o_i: occupancy of the traffic network link i

f_i: flow of the traffic network link i

m: dimension of the junctions (each junction m have pm stages, not necessary the same)

$g_{j,k}$: effective green time of the stage k in the junction j

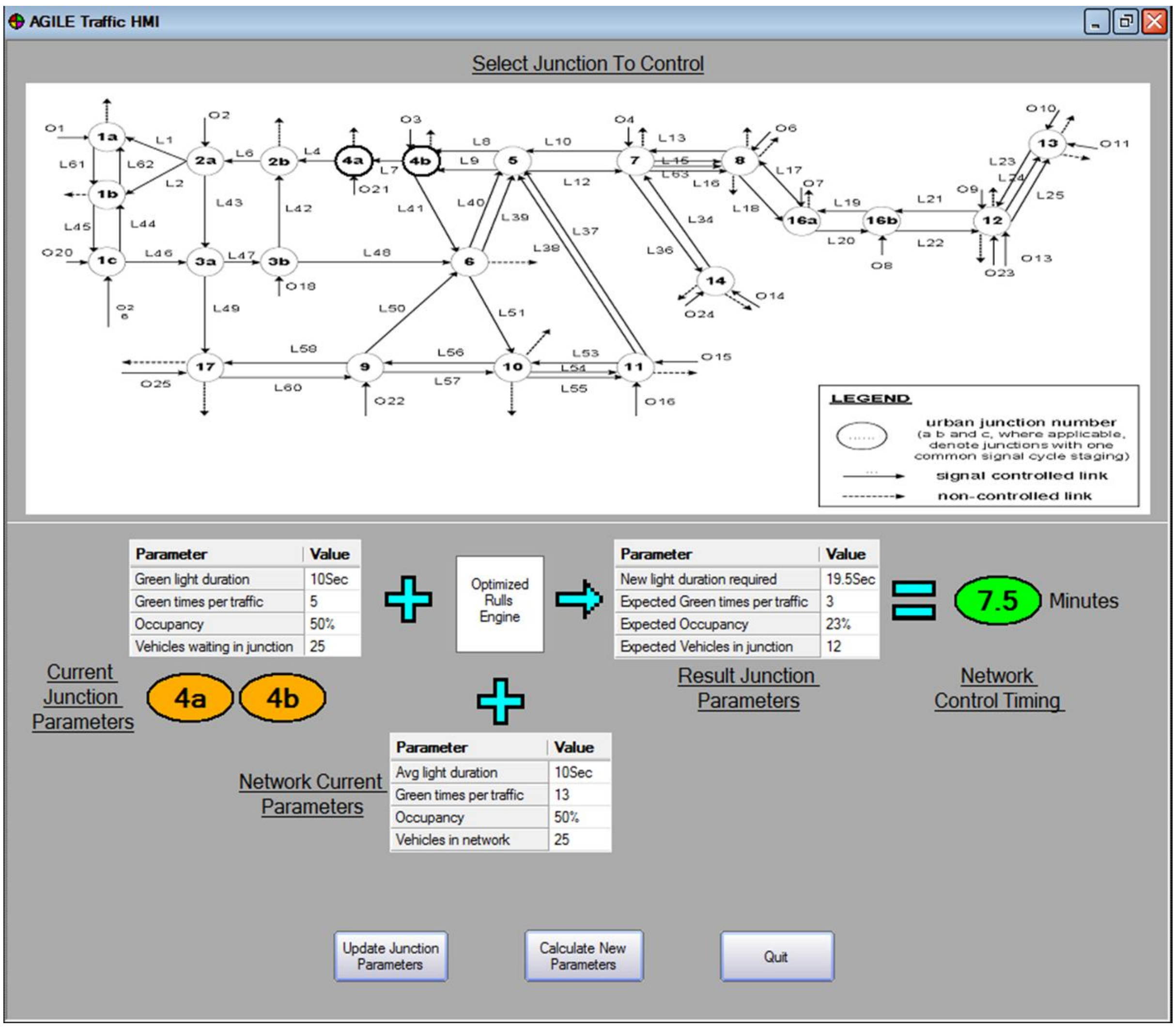
q_i: number of vehicles entering the network origins and other points

3.2.4 HMI to Chania UTC

Here it is shown a picture that describes the purpose of the AGILE controlled algorithm, according to its roles and constraints. First of all, there is a picture of Chania city Centre signalised network with its traffic junctions on it. After filling the current measured parameters of all junctions, the AGILE system calculation results should change junction's parameters, for all junctions in the network.

This HMI will make the interface with the SCADA system simpler – sensors will collect the junction's parameters, and should be able to update their parameters according to AGILE algorithm results. Communication and network protocol interface layer should be developed (if it would be necessary) to support the necessary data exchange between the system and the junction's sensors and/or activators.

In the example the tested junction is 4a, 4b junctions with obviously no real numbers.



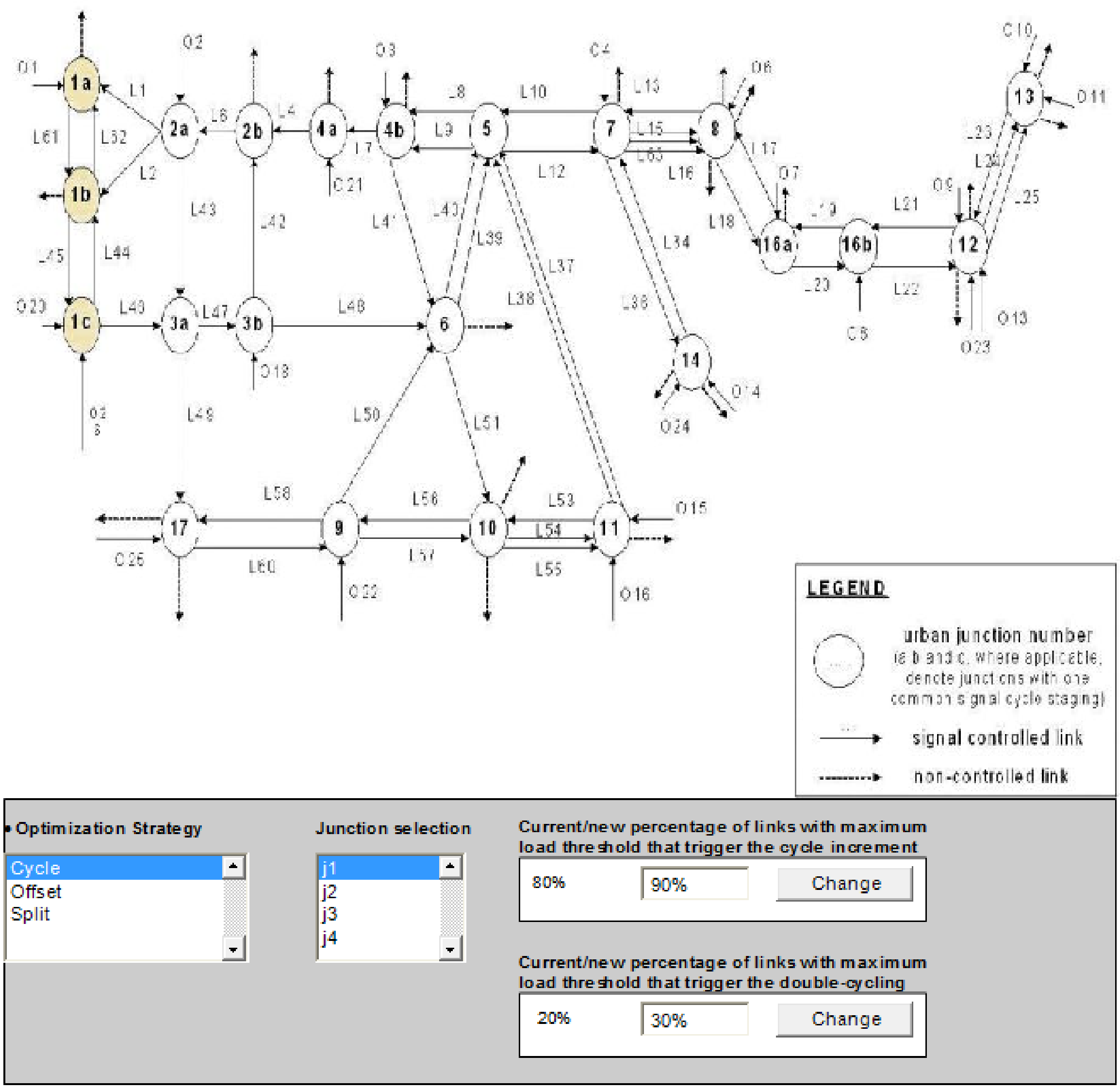
The HMI should control characteristics related to the TUC modules: cycle, offset and split.

For each of these modules many thresholds are selected just to tune the system and consider the rules expressed in the 5.1 deliverable.

CYCLE:

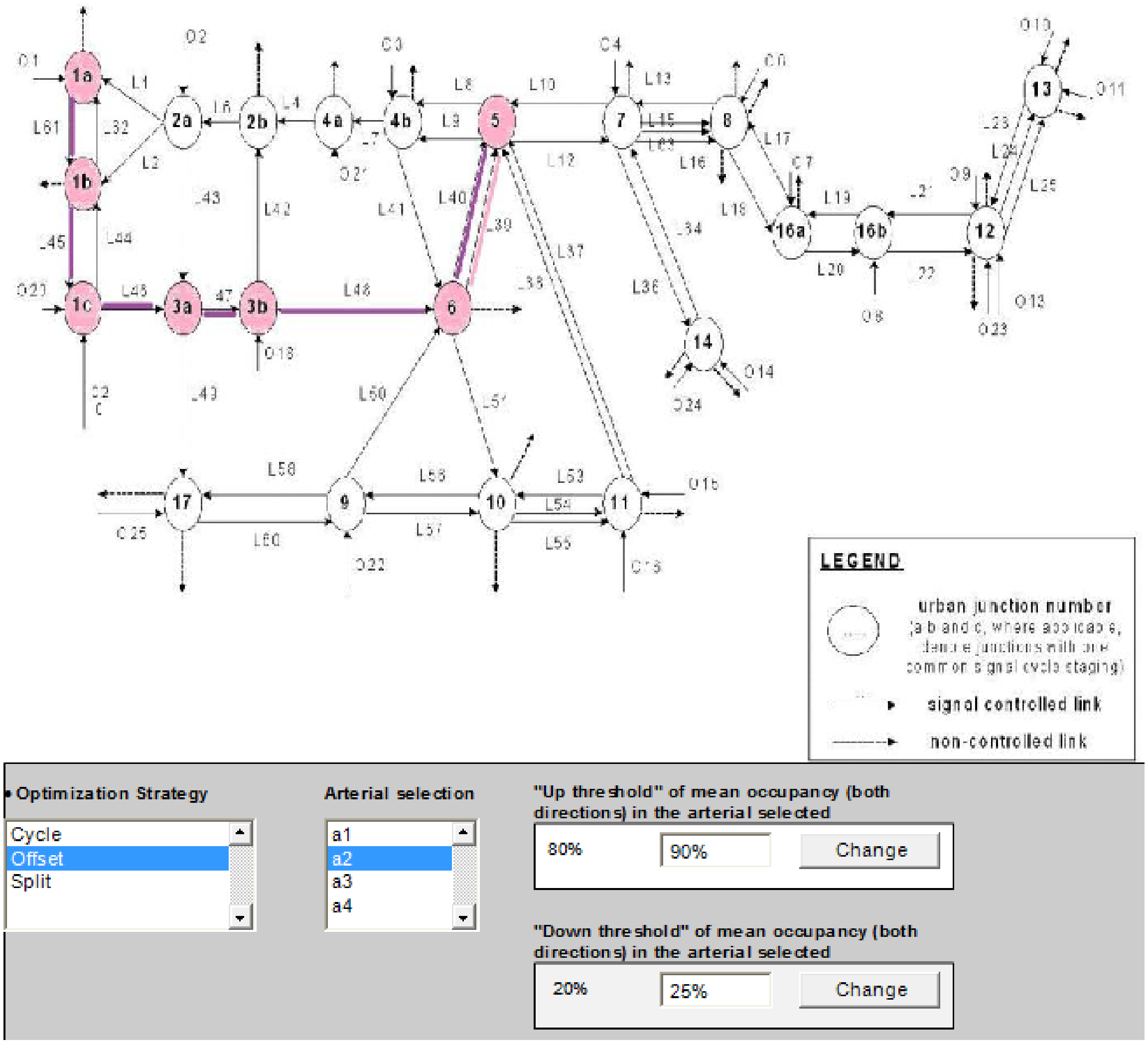
In this case, after a junction is selected (e.g. Junction 1), there is a percentage threshold that indicate, for each junction (or arterial or even for the whole net, that must be studied), that the cycle time must be greater just to increase the capacity of the junction. The operator can change this percentage threshold.

When we find in under-saturated junctions, is useful to double-cycling. We can tune this situation changing other threshold for every junction (or arterial).



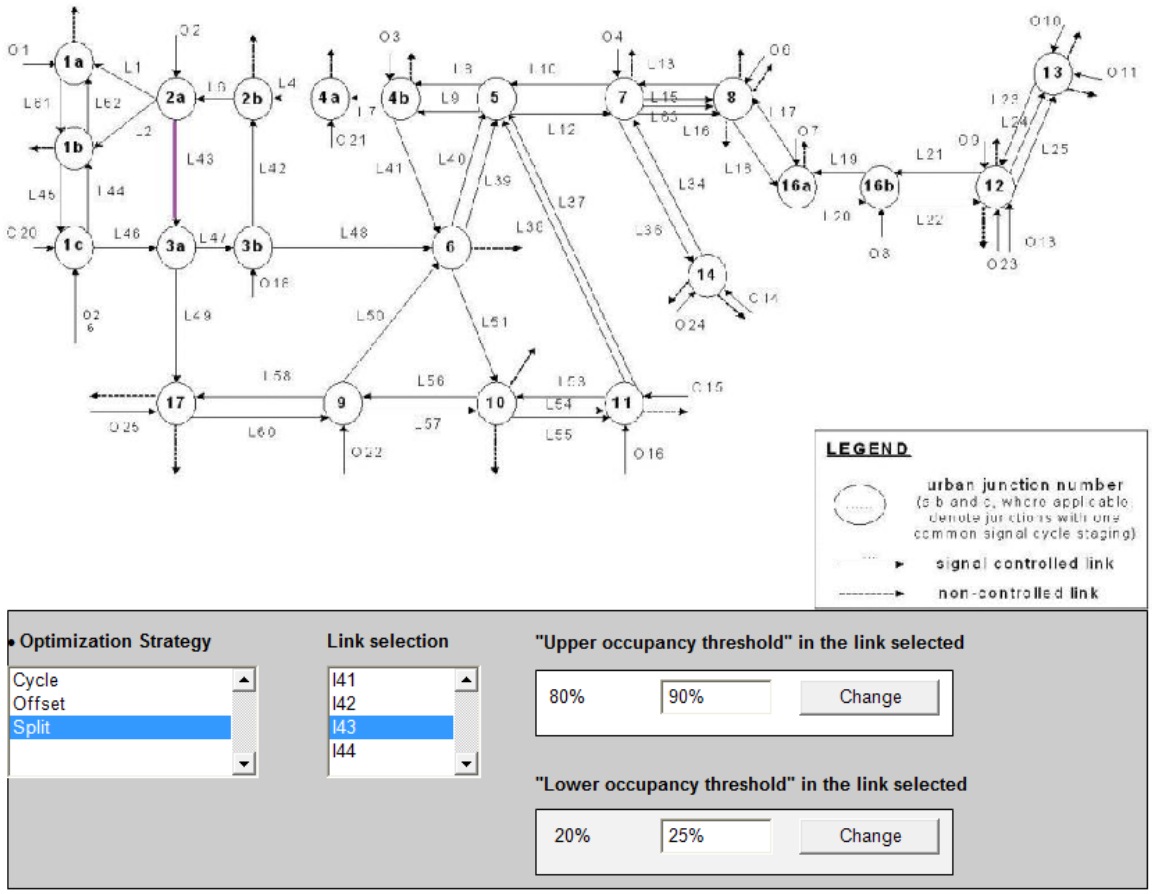
OFFSET:

Related to the offset module the link's arterials are the main entities. If the mean occupancy of an arterial exceeds an "up threshold" (a serious queue is detected), the offset is increased. If the mean occupancy of an arterial is below the "down threshold", the offset is reduced. Both thresholds are managed from the HMI. Combinations of different occupation depending on the direction make necessary more controls.



SPLIT

The rules relate to the split module have to tune each link. After a link is selected, there will be a link occupancy threshold. If the link occupancy exceeds this threshold, the "importance factor" is increased. This design parameter increases the importance (the measured average time-occupancy) of a specific link. If the link occupancy is below the threshold, the "importance factor" is reduced.



GENERAL COMMENTS

It could be shown also real time information in the HMI like "latest available numbers of vehicles in a link selected", "Green time in the right of way (r.o.w.) selected", "Cycle time in the junction selected",… but in this case, it will be information that will not be modified.

3.2.5 Rules tables

In order to define the "if-then" rules that will be included in the model, we start with:

Junction (capacity) > 90% Calculate new green times based on the capacity the different accesses to the junction translated to variables, number of

This condition could be expressed so:

o_i , f_i are the occupancy and flows of the traffic network link i

$\Sigma\, o_i > OL\{j,i\}$ (=Occupancy limit of the junction j) or maybe, each traffic network link has a different weight (in this case will be a coefficient for every addend)

$\Sigma\, f_i > OF\{j,i\}$ (=Flow limit of the junction k) or maybe, each traffic network link has a different weight (in this case will be a coefficient for every addend) to calculate each cycle.

We should increase the effective green time of **the next stage j: g_j_k** (following the nomenclature)

The following tables should be translated to an automatic SW tool and should be read as follows:

If {(measurement (condition) constant) AND/OR (measurement (condition) constant) AND/OR (….)} THEN action.

3.2.6 Cycle modification rules

#	Measurement	Condition	Constant	AND/OR	Measurement	Condition	Constant	AND/OR	Action	Remarks
1	Region(capacity)	>	90%	OR	50% of junction(capacity)	>	90%		Increase cycle	50% percent of the junctions in the zone must have a capacity over 90%
2	Region(capacity)	<	80%						Decrease cycle	
3	Density	>	90%						Increase cycle	

3.2.7 Offset modification rules

#	Measurement	Condition	Constant	AND/OR	Measurement	Condition	Constant	Action	Remarks
1	Offset arterial (mean occupancy both directions)	>	80%					Increase offset between junctions	A serious queue is detected
2	Offset arterial (mean occupancy both directions)	<	70%					Decrease offset between junctions	No serious queue is detected
3	Offset arterial (mean occupancy direction 1)	< (>)	50%	AND	Offset arterial (mean occupancy direction 2)	> (<)	50%	Decrease weight for direction 1 (2) and increase weight for direction 2 (1)	Direction 1 (2) is less congested than Direction 2 (1)

3.2.8 Green time modification rules

#	Measurement	Condition	Constant	AND/OR	Measurement	Condition	Constant	Action	Remarks
1	Link (occupancy)	>	80%	AND	50% time of the day (occupancy)	>	70%	Increase importance factor	This is an important link
2	Link (occupancy)	<	10%	AND	50% time of the day (occupancy)	<	20%	Decrease importance factor	This is not an important link

3.2.9 Incident modification rules (malfunction/ incident/congestion detection)

#	Measurement	Condition	Constant	AND/OR	Measurement	Condition	Constant	Action	Remarks
1	Detector (Occupancy)	>	100%	OR	Detector (Occupancy)	<	0%	Ignore measurements	Detector failure
2	Region (mean speed)	<	10 km/h					Enable upstream gating to protect downstream areas from gridlock	Serious traffic jam
3	Arterial (travel time)	>	1.5 * TTS					Appropriate message via VMS	TTS is the mean travel time in the region

3.3 Energy Positive Building

3.3.1 Input/output parameters, constraints, rules for ZUB building

Measured parameters table (estimation of existing sensors):

#	Outside	Building	At each room	Remarks
1	Temperature	Temperature	Temperature	
2	Air moisture	Humidity	Humidity	
3	Sun radiation	Illumination	Illumination	
4		Air quality (CO_2)	Air quality (CO_2)	Vary due to occupancy
5	Wind direction			
6	Wind speed			
7			Occupancy	Computer energy consumption is constant

Temperature Comfort parameters (constraints):
http://www.ccohs.ca/oshanswers/phys_agents/thermal_comfort.html

Parameter	value	Remarks
Temperature	21-23°C	
Humidity	50%	± 15%
Air speed	< 2.5M/S	
Air quality	~600 ppm	(CO_2) dependable on occupation and building location

The CO_2 concentration is proportional to the actual number of occupants at a given time in the room. It also depended on the building location (nearby urban centers or near industrial plants) where the quality of the outdoor air may be worse than that of the indoor air. The cleaning of internal air filters is important, to remove contaminants from both the ventilation (outdoor) and indoor air.

There are three strategies for achieving acceptable indoor air quality: ventilation, source control and cleaning/filtration. Depending on the building and the specific characteristics of its location, these strategies may be used singly or in combination.
Source: http://www.nrc-cnrc.gc.ca/eng/ibp/irc/ctus/ctus-n33.html

3.3.2 Parameter's dependable table for an office room:

Parameter	Forced Ventilation	Natural Ventilation	Heating/ Cooling	Shading	Illumination	Remarks
Temperature	+/-	+/-	+	-	NA	Ventilation depends on outdoor weather. Temp reduced while shading (shutter down) but increased when blind is opened and no shutter is up
Humidity	NA	+	-	NA	NA	Humidity reduced while heating or cooling
Illumination	NA	NA	NA	+	+	Depend on room occupation
Air quality	+	+	-	NA	NA	Increased when window is open or forced ventilation
Energy	+	-	+	-	+	Increased when forced ventilation, cooling, heating or illumination

The total energy required should calculated as: $E_{(T)} = E_{(HVAC)} + E_{(Illumination)}$

When:
$E_{(HVAC)}$ = the total energy required by the HVAC electricity engines and apparatus,
$E_{(Illumination)}$ = the total illumination electricity power required for the whole building

The project goal is to achieve the minimum total energy as possible at comfort temperature.

The following estimations were made of existing controlled components:

1. At any room:
   a. Heating valve between 0 – 100% (0 = close, 100 = full open)
   b. Cooling valve between 0 – 100% (0 = close, 100 = full open)
   c. Window blind (shutter) that can be up or down 0 – 50% (0 = up, 50 = down)
   d. Window blind (angle) that can be turned 0 – 100% (0 = dark, 100 = full solar radiation)
   e. Window opening (manual or automatic) 0 – 100% (0 = close, 100 = full open)
   f. Room forced ventilation – via central system: type A
   g. Room forced ventilation – via central system: type B
   h. Room air moisture will be changed through ventilation process

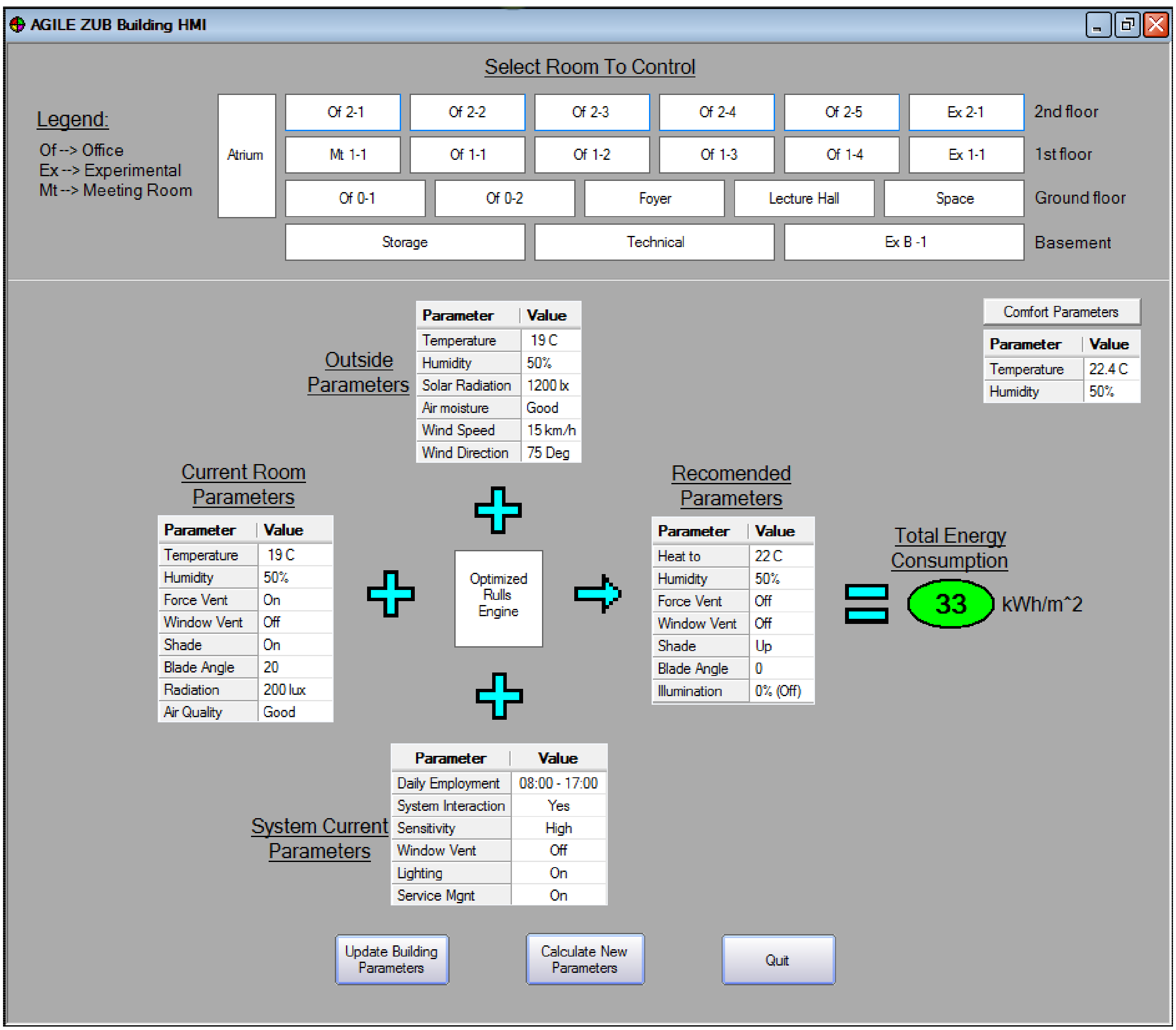
Building automated components:

i. Heating system 0 – 100% (0 = close, 100 = full open)
j. Cooling system 0 – 100% (0 = close, 100 = full open)
k. Forced ventilation system – type A
l. Forced ventilation system – type B
m. Illumination dimming control 0 – 100% (0 = off, 100 = full illumination)

According the parameters above, the intuitively rules for working hours and energy reducing were created. For day/night and non-working hours the temperature/humidity parameters are different, thus preference for ventilation is assumed in those hours.

3.3.3 HMI to ZUB building

A recommended HMI to describe calculation processes is as follows:



3.3.4 Rules tables

The following tables should be translated to an automatic SW tool and should be read as follows:

If {(measurement (condition) constant) AND/OR (measurement (condition) constant) AND/OR (….)} THEN action.

3.3.5 Ventilation operation rules:

#	Measurement	Condition	Constant	AND /OR	Measurement	Condition	Constant	AND /OR	Action	Remarks
1	Room temp	>	24^0C	AND	outside temp	≤	23^0C	AND		
	room air quality	>	600ppm	AND	wind speed	≤	10km/h		open window	
2	Room temp	<	21^0C	AND	outside temp	≥	22^0C	AND		
	room air quality	>	600ppm	AND	wind speed	≤	10km/h	-	open window	
3	Room humidity	>	60%	AND	Outside air moisture	=	Low	-	open window	
4	Room humidity	<	40%	AND	Outside air moisture	=	High	-	open window	
5	wind speed	≥	10km/h	-	-	-	-	-	close window	

Note:
Room air quality may calculate as 600ppm per person

3.3.6 Cooling rules:

#	Measurement	Condition	Constant	AND /OR	Measurement	Condition	Constant	AND /OR	Action	Remarks
1	Room temp	>	24^0C	AND	outside temp	≥	24^0C	-	Start cooling	
2	Room humidity	>	60%	AND	Room temp	≥	24^0C	-	Start cooling	
3	Room temp	>	24^0C	AND	outside radiation	=	Low		Start cooling	No ventilation allowed, nor illuminating

3.3.7 Heating rules:

#	Measurement	Condition	Constant	AND /OR	Measurement	Condition	Constant	AND /OR	Action	Remarks
1	Room temp	<	21^0C	AND	outside temp	≤	21^0C	-	Start heating	
2	Room humidity	<	60%	AND	Room temp	≤	21^0C	-	Start heating	
	Room temp	<	21^0C	AND	outside radiation	=	Low	-	Start heating	

Note:
For energy saving, cooling/heating should start after ventilation is OFF, and room's windows are closed.

3.3.8 Illumination and shading rules:

#	Measurement	Condition	Constant	AND /OR	Measurement	Condition	Constant	AND /OR	Action	Remarks
1	Outside light	=	High	AND	Room light	=	High	AND		
	Room temp	>	24^0C	-	-	-	-	-	Shutter down	start shading
2	Outside light	=	Low	AND	Room light	=	Low	-	Shutter up	stop shading
3	Outside light	=	Low	AND	Room light	=	Low	-	Lights ON	
4	Outside light	=	High	AND	Room light	=	High	-	Lights OFF	
5	Room temp	<	21^0C	AND	outside radiation	=	High	-	Shutters up	full radiate
6	Room temp	<	23^0C	AND	outside radiation	=	High	-	turn on blinds	full radiate
7	Room temp	>	24^0C	AND	outside radiation	=	Low	-	turn off blinds	stop radiate

3.4 Interchange Station Management

3.4.1 Background

Interchange Station Management System (ISMS) like other similar LSCS (train, underground station management) are systems that include many sensors and actuators providing a wide range of operative and security functionality.

Although the Interchange Station Management System is designed to meet mainly operation and maintenance issues, it is operated from the Central Control Station using 3 different operators (Traffic, Security and Maintenance) and many other agents and systems are present and interrelate.

In this section, we describe how AGILE project can be used in this type of LSCS including and algorithms and monitoring command and control center using a rule engine.

The ISMS is a system for integrated management and monitoring of bus and underground movements and signaling, as well as planning train routes, and all the station infrastructure (lifts, phones, doors, heating, lighting, ANPR,…).

It is compound a a group of facilities to centrally monitor and control each subsystem in real time, receive alarms, record operational data and produce performance reports. Energy management software eliminates unnecessary power usage. Monitoring provides quick response to problems and secures facility operation.

In effective ISMS, the objectives should be:

- Control the convenient temperature of the halls and other dependencies
- Control of the air quality in the close areas
- Real time monitoring of all the systems
- Reduce the time of the buses in platforms
- Reduce the passengers affluence in the access areas (the last two objectives could be considered in a global optimization of business opportunities)

The management process consists of five interrelated elements within a regulatory framework:

- Real time monitoring system
- Air quality management;
- Management of infrastructure assets; and
- Optimization of business opportunities.
- Incident management

3.4.2 Real time monitoring system / Traffic management

This subsystem registers and monitors every movement of the buses according to a schedule and taking in account safety and emergency criteria. It includes identification and location tasks and interacts with other infrastructure asset like interphone, heating systems, etc
Apart from the monitoring issues this system controls all type of access infrastructure which interacts with the traffic management:

- Barriers used for security reasons
- Gates in the access points

- Bus access doors: Doors in the access tunnels to prevent entry into the station when it is closed
- Pedestrian gateways in emergency exits
- Access Doors Screens: Gates of screens deployed on the islands of docks to physically separate the movement area of bus and passenger waiting area
- Tunnel deployment (CTV, access barrier, atmosphere control, radio RDS information …)
- Dock occupancy sensors

3.4.3 Air quality management

Air quality management will involve:

- Ventilation System management. It consists of proper ventilation equipment, and also the detectors to monitor pollution levels.
- Monitoring, analyzing and reporting on air quality;
- Risk management and the development of contingency plans in the event of adverse events that have an impact on air quality.

3.4.4 Management of infrastructure assets

This subsystem includes the following elements:

- Close-circuit Television CCTV
- Megaphone: system responsible for informing users of the interchange traffic and / or safety.
- Intercom: Intercom system for employees or users themselves can communicate with the central control station of the interchange station
- Elevators and escalators
- Lighting
- Energy monitoring (power distributions and energy management)
- Heating/Cooling
- PCI (fire detection systems)

3.4.5 Optimization of business opportunities

A group of sensors (among them the ANPR - Automatic Number Plate Recognition, occupancy dock sensors,…) make possible the efficient management of the platforms areas. In case of buses or people congestion, this subsystem will accurate control the affected areas through infrastructure management (megaphone, gates,…) and dynamic association of docks.

3.4.6 Incidents management

Incidents are recorded from different notifications systems, as well as operators and modules. Each reported incidence may be associated with different actions of other systems or modules. In some cases, an operator must validate in order to confirm the actions and maneuvers associated and he has to be informed in real-time about the incidents.

These systems generate a huge amount of rules (so called operating plan) that will be managed in an automatic or manual way. Therefore, a rules engine could be implemented in charge of performing automatic actions and timetable set by scenes on the various systems mentioned (on or off lighting or power). A scene is defined as a group of orders that apply to different systems. The setting of schedules and / or scenes performed by the operator of the distributed system. These scenes are translated to our AGILE language as a *"rule"*. Identification system registers vehicles entering the station by sending such information to the "rules engine". In the case of an unauthorized vehicle generates a notification. The movements and actions of each vehicle inside the station provide valuable information that can be affected by a "rule".
As in the traffic control system and the energy efficiency building test cases, it will be easy to translate these scenes in

> ***IF*** {(measurement (condition) constant) ***AND/OR*** (measurement (condition) constant) ***AND/OR*** (….)} ***THEN*** action

Sentences, joined to different actions. Here we have many examples of this type of rules:

#	Measurement	Condition	Constant	AND/ OR	Measurem ent	Condit ion	Cons tant	Action	Remark s
1	Plate number vehicle	!=	List of authorize d plate number					Alarm ON. Open exit gates	A notificat ion is generate d
2	GPS coordinates of the vehicles	= (belongs to determina ted areas)	Allowed parking docks and corridors					Alarm ON	A notificat ion is generate d
3	Temperature in the dock´s area	<	18					Switch the heating system	
4	No bus in a particular dock	>	300 seconds					Decrease the light intensity. Switch on the dynamic association of docks	

#	Measurement	Condition	Constant	AND/ OR	Measurem ent	Condit ion	Cons tant	Action	Remark s
5	Dock assigned	=	“BUSY”	AND	Bus assigned occupancy	<>	0%	Assign the first regulation dock	Also an indicati on to the bus driver “Go to regulati on dock”.
6	CO	>	25 ppm	OR	CO2	>	800 ppm	Increase the ventilation systems speed	

3.5 Interurban Traffic Control System

3.5.1 Background

Interurban Traffic Control System forms a wide range of systems. Here will be detailed a system with the main objective is offering traffic expertise, hazard recognition and control measurements for a controlled region.

The Control Centre provides a system for handling incidents and alarms, to monitor and respond quickly to events that occur in everyday life and includes also all the functionality required for traffic monitoring and control in highway entrances and exits.

The system can set the plans that are required for the management of equipment and subsystems. The control mode can be semi-automatic or automatic.

Additionally, it stores historic data of the evolution of signals, alarms, incidents, and operator actions. These records allow the generation of reports of the status and events of equipment. These reports are useful for the operation of the system.

The workstations (with software application) are installed in each operation control system to allow the operator to get dynamic information of the status, values, alarms and incidents provided by low level equipment, and ability to control equipment and management of incidents.

The Control Centre shows in the monitor information from the field subsystems:

- Meteorological Data
- Traffic Counter Data
- CCTV images
- VMS

The Control Centre integrates all information coming from the equipment and displays outgoing information. It provides easy and convenient ways to visualize and control VMS, real-time measurements of traffic and road weather variables. These measurements constitute the main input to traffic engineering models that are solved to estimate the current state of the network and forecast its short-term evolution.

The models merge heterogeneous, overlapping data from different sources, to offer a sound state estimation for the links in the road network and to provide a consolidated knowledge base for the decision models. The integration of floating car data adds value in terms of traffic state estimations. It helps to detect congestions that were “overlooked” by the stationary detectors or to give more detailed information of the location of congestion.

Important part of the traffic management system are also the decision-making functions that assists the traffic operators in selecting the most appropriate management strategy to solve identified traffic problems. A further functionality is informing the drivers in a timely and appropriate manner.

An important requirement consists on the maintenance of efficient Level of Service (LoS). This level will be a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and journey time, freedom to manoeuvre, traffic interruptions, and comfort and convenience.

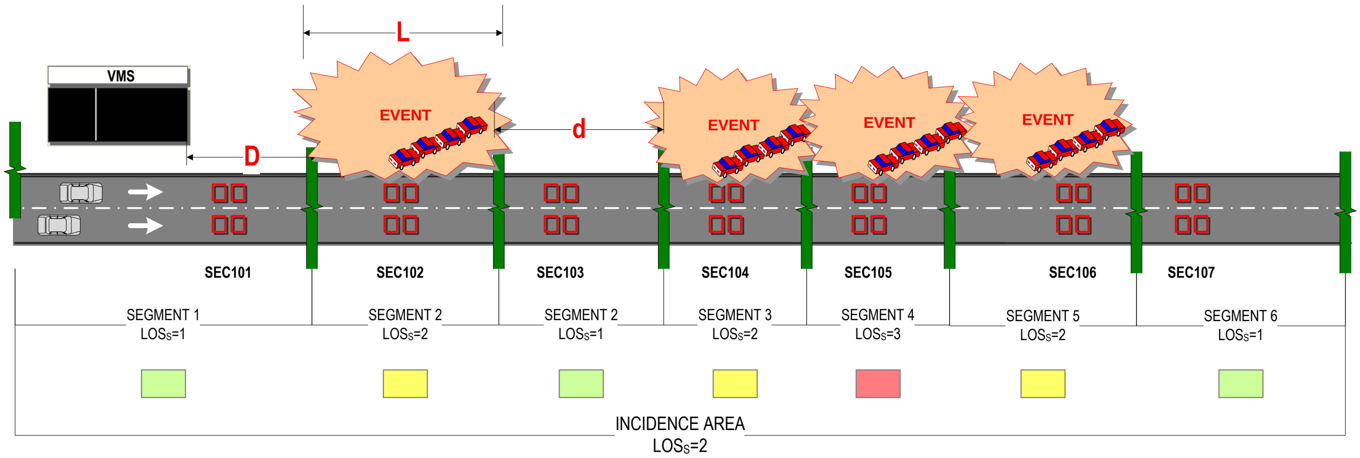
There are a set of algorithms that gives the correct output to the drivers (speed recommendation, incident information, travel times,…)

The restrictions in this system are:

- The system adjusts dynamic speed limit by stages (120, 100, 80, 60 km/h) during heavy traffic periods and achieve efficiently improve of safety of road and a decrease of stop and go situations.
- The traffic management will be accompanied of a forecast weather information system, which enables assessment the influence of weather conditions in a strategic traffic management and act based on those results.
- The system will be able to activate planned or suggested control strategies, according to the results generated by all the algorithms on the basis of traffic and weather conditions.
- The information will be disseminated to the drivers via infrastructure based VMS.

The specific indicators in the system are:

- Average speed and compliance of “dynamic speed limits” by drivers
- Traffic volume flow and traffic capacity
- Reduction of congestion (number, length duration)
- Evaluation of “Stop and Go” situations
- Number of accidents
- User satisfaction and acceptance of the service
- Validation of the quality of the weather information



Traffic flow and incidents in a highway stretch

3.5.2 Input/output parameters, constraints, rules for Interurban Traffic Control System

Measured parameters table (estimation of existing sensors):

#	Resource	Catchment	Infrastructure	Remarks
1	Intensity		Traffic Counter	Indicate congestion
2	Speed		Traffic Counter	Indicate congestion
3	Occupancy operational		Traffic Counter	Indicate congestion
4	Temperature		Weather sensor	Could indicate ice
5	Wind speed		Weather sensor	
6	Crash		CCTV	Crash type (spin-out, rollover)
7	Other incidents		CCTV	Detection of vehicle in the opposite direction,…

3.5.3 Rules tables

The following tables should be translated to an automatic SW tool and should be read as follows:

If {(measurement (condition) constant) AND/OR (measurement (condition) constant) AND/OR (….)} THEN action.

Today there is only few rules to demonstrate the process of using a resource according to its quality (calculated number), resources supplying capabilities over time, recreation and refilled needs and so on.

If a need will rise – more rules will be added.

3.5.3.1 Operation Rules:

#	Measurement	Condition	Constant	AND /OR	Measurement	Condition	Constant	AND /OR	Action	Remarks
1	Intensity	>	70%	AND	Occupancy	>	2000veh/h		Usage VMS informing about recommended speed 80 km/h	
2	Temperature	<	0	AND	Wind speed	>	60	-	Usage VMS informing about risky situation	
3	Speed	<	0						Usage VMS informing about risky situation (vehicle in the opposite direction)	There are

3.6 Water Resources Management

3.6.1 Background

For everyone around the world, water is a critical resource for all aspects of daily life – for people to live, for countries to grow and develop, and for our environment to survive.

In this section, we describe an implementation of the AGILE project and algorithms so it will fit the water resources management, in a holistic algorithm and smart system to monitor command and control center. We will mainly focused and consider the drinking water processes and constraints, but it should be enlarged to gray water (the water which is the bathroom outcomes) and desalinated water. The latter is used mostly in plants irrigation and other agriculture areas.

The outcomes from the implementation of effective water source management should be:

- water sources of quantity, quality and reliability that will meet a WSP's (water service provider) current and future requirements;
- regulatory compliance

Outputs from the water resource management process should include:

- Water resources usage – scheduling, quantity and replacements from each resource
- Water allocation approvals according their supplement capability
- Water quality approval – at each resource and infrastructure

Water sources can be classified as:

- Surface water resources – rivers, catchment, rain/snow water cistern, spring
- Groundwater sources – aquifers
- Water purchased from another WSP.

A reliable, quality water resource is one of a WSP's most critical assets. Failure of supply, in terms of both quality and quantity, can have serious implications for customer service and the business.

3.6.2 The water resource management process

Water source management consists of four interrelated elements within a regulatory framework:

- management of water resource reliability;
- water quality management;
- management of infrastructure assets;
- Optimization of business opportunities.

3.6.3 Management of water resource reliability

To achieve this, it is important to have an understanding of the sources of water supply including:

- assessing future raw water requirements and identifying and pursuing available sources and allocations
- developing and implementing formalized operating rules for storages, detailing how the storage would be operated to meet WRP outcomes regarding environmental flows (where appropriate)
- operation of the sources (ground and surface water) to meet customer demands during normal and abnormal (e.g. drought, mineral types and levels) conditions
- reducing water losses from sources (e.g. capping of bores within the Great Artesian Basin)
- maximizing water available from headwork
- Investigating opportunities that may exist for water trading.

3.6.4 Water quality management

Over the past few years both the urban and rural water industry have suffered increasingly from the deterioration of raw water quality. Problems have included blue-green algae outbreaks, giardia, cryptosporidium, increasing turbidity and salinity, and excessive growth of noxious weeds. There have also been increasing incidences of groundwater contamination from nitrates. Effective management of catchments and water storages can provide considerable water quality improvement. Water quality management will involve:

- proactive involvement in integrated catchment management initiatives;
- proactive input into land use planning;
- monitoring, analyzing and reporting on water quality;
- operating intakes to abstract the optimal quality water;
- improving water quality through desertification (where appropriate);
- managing recreational activities to minimize impacts on water quality and the natural
- environmental
- Risk management and the development of contingency plans in the event of adverse events that have an impact on water quality.

3.6.5 Management of infrastructure assets

Water source infrastructure such as dams, weirs and bores would be included in a WSP's planned maintenance program and documented operation procedures. These assets would be given a high level of importance, thus justifying investment in maintenance. Many of these requirements are essentially good practice and could also be applied at an appropriate level to non-referable dams.

3.6.6 Optimization of business opportunities

Where a WSP is supplied bulk water from another WSP a formal agreement will exist between the parties, which will cover matters such as water quantity, quality, reliability, pricing, payment, flow measurement, communication processes and conflict resolution.

3.6.7 Target Water Source Management Mechanism

The management mechanism should be performed periodically, according the variable customer's needs. In case of the simple example below – where only four resources exists, the quantity from any resource depends on its flow capabilities, and its last measured quality. Two or more resources can be joined together to fulfilled the needs.
To save the resource quality (e.g. turbidity, salinity), the resource should supply less than its capabilities, by pumping flow amount or periodically interrupted pumping – let the resource recreation in between pumping.
There are some more considerations constraints:

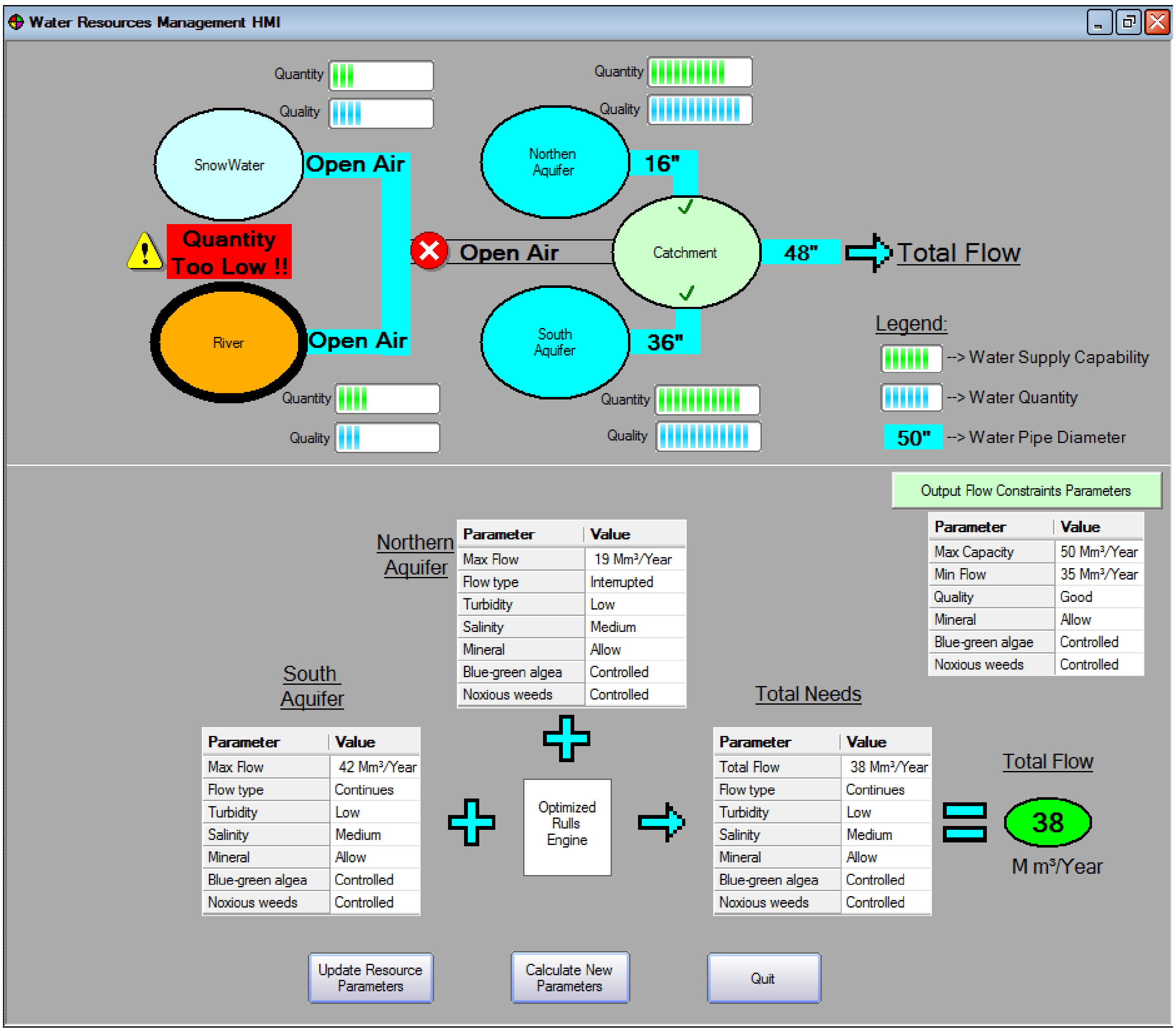
- Min flow: there a minimum water to supply from this catchment – otherwise an water overflow will occur
- Since the snow water and the river almost dry, their quantity alarm are "ON", and the catchment close the water income valve, closing water entering from the open air watercourse.
- Quality is a calculated number which is calculate the mineral measurement values, turbidity and salinity and weeds (all kinds), each if which in importance weight. The outcome number should tell (0-100%) the total drinking water quality.
- The calculation presented here are for one catchment water resource management. The same calculations should perform to each catchment in the county, province, and for the whole country.

According the above, the software algorithm should support the following needs:

- Future water requirements assessed and allocations secured.
- Catchment and/or aquifer recharge area land used.
- Emergency response plan in place for major catchment/recharge area pollution events
- Storage recreational used.
- Storage operational used.
- Controlling aquatic plants and cyanobacteria, such as blue-green algae.
- Source water quality monitoring.
- Periodic infrastructure maintenance (cleaning, replacements and anti-bacteria treatment of pipes, watercourse, pumps etc.)

3.6.8 Water Resource Management HMI

A recommended HMI to describe the Water Resource Management System is as follows:



3.6.9 Input/output parameters, constraints, rules for Water Resource Management

Measured parameters table (estimation of existing sensors):

#	Resource	Catchment	Infrastructure	Remarks
1	Capability	Capability	Capability	Assuming that Resource capabilities < Catchment capabilities
2	Storage recreation	Resource management	NA	Impact on resource usability type
3	Storage operational	Resource management	NA	Impact on resource usability type
4	Controlling plants and cyanobacteria	Controlling plants and cyanobacteria	Controlling plants and cyanobacteria	Impact on water quality
5	NA	Periodic maintenance	Periodic maintenance	Impact on water quality
6	Turbidity	Turbidity	NA	Impact on water quality
7	Salinity	Salinity	NA	Impact on water quality

3.6.10 Rules tables

The following tables should be translated to an automatic SW tool and should be read as follows:

If {(measurement (condition) constant) AND/OR (measurement (condition) constant) AND/OR (….)} THEN action.

Today there is only few rules to demonstrate the process of using a resource according to its quality (calculated number), resources supplying capabilities over time, recreation and refilled needs and so on.

If a need will rise – more rules will be added.

3.6.10.1 Operation Rules:

#	Measurement	Condition	Constant	AND /OR	Measurement	Condition	Constant	AND /OR	Action	Remarks
1	Resource Capability	>	Customer needs	AND	Resource Quality	≥	Customer requirement	AND		
	Storage recreation	<	Current flow	AND	Storage operational	=	Continuous	-	Usage continuous allow	

3.6.10.2 Using Periodic Resource Rules:

#	Measurement	Condition	Constant	AND /OR	Measurement	Condition	Constant	AND/ OR	Action	Remarks
1	Resource Capability	>	Customer needs	AND	Resource Quality	≥	Customer requirement	AND		
	Storage operational	=	periodic	AND	Elapsed Time measured	≥	Pumping time	-	Stop using the resource	

4 Performance requirements and constraints which AGILE can efficiently and automatically address but the existing LSCS designs embedded in SCADA/DCSs are not able to automatically or efficiently handle

AGILE can handle any performance requirement and constraint that involves any nonlinear function of the system sensor measurements and/or controls. These types of requirements and constraints cannot be – in general – handled by conventional SCADA/DCS systems. For instance constraints of the type

Average Traffic Network Speed>XX kmh

for AGILE Test Case 1, or

Fanger PPD (Predicted Percent of Dissatisfied<XX %

for AGILE Test Case 2

cannot be directly incorporated within existing SCADA/DCS systems as both ***Average Traffic Network Speed*** and ***Fanger PPD (Predicted Percent of Dissatisfied*** are highly nonlinear functions of the sensor measurements.

5 Transforming the rules in an AGILE form

It will be shown how a rule–based control system (test site 1) can be transformed into an AGILE compatible format.

Chapter 7 (ANNEX1) shows how the rules-based control system currently works. Extract from this model, there are many rules in the 5.1 deliverable. It is necessary the conversion from linguistic to functional. We proceed with this description including examples which cover many types of rules and restrictions.

5.1 Converting linguistic rules to optimization Constraints

Regarding the conversion of restrictions imposed to control variables expressed in linguistic IF-THEN form, we may devise an appropriate functional involving variables of the IF and possibly of THEN part. A useful approach is to consider how fuzzy inference is performed and how this can be used to produce this functional. Then the conversion to some kind of inequality (s) is straightforward.   Let's see the various steps.

1st step: We decide which functions have to be used for accessing linguistic statements involving numbers. For example, the statement ***variable* is *value*** (temperature is 30^{o}) can be tested for its validity by considering a function which measures how close to *value* is the variable. The following functions can measure how close to 15 is variable x. See their performance in Fig. 1. Alternatively, one may use a relatively "narrow" Gaussian centered at 15.

$$f(x)=\frac{1}{1+(x-15)^4},$$

$$f(x)=\frac{1}{1+(x-15)^2}$$

Eq. (1)

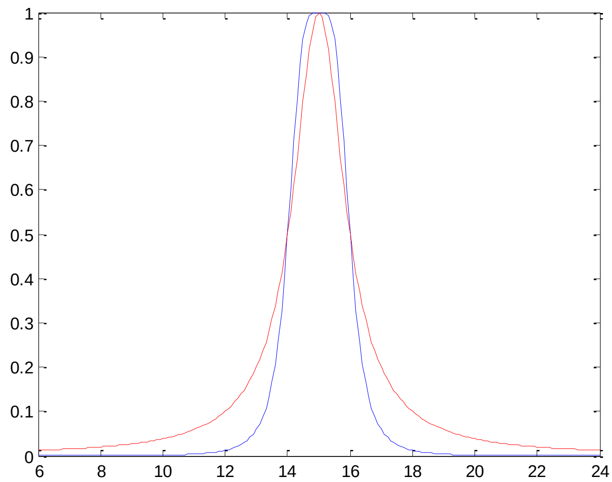


Fig. 1. evaluation of 'x is approximately 15' - blue = power of 4, red = power of 2

Likewise, for evaluating the statement ***x is greater than 15*** we may use the piecewise continuous function

$$f(x)=\begin{cases}\dfrac{1}{1+(x-15)^{-2}}, & x>1\\ 0, & x\leq 15\end{cases}$$

Eq. (2)

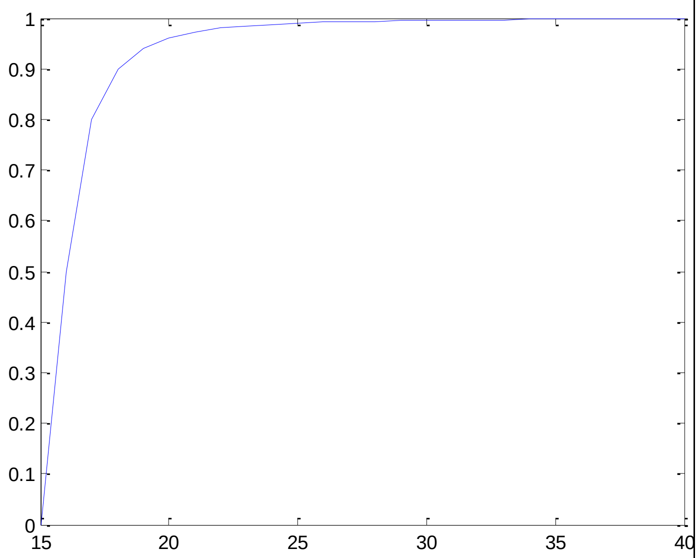


Fig. 2. Evaluation of 'x is greater than 15'

or a relatively sharp sigmoid

$$f(x)=\frac{1}{1+e^{-c(x-15)}},\quad c>1$$

Eq. (3)

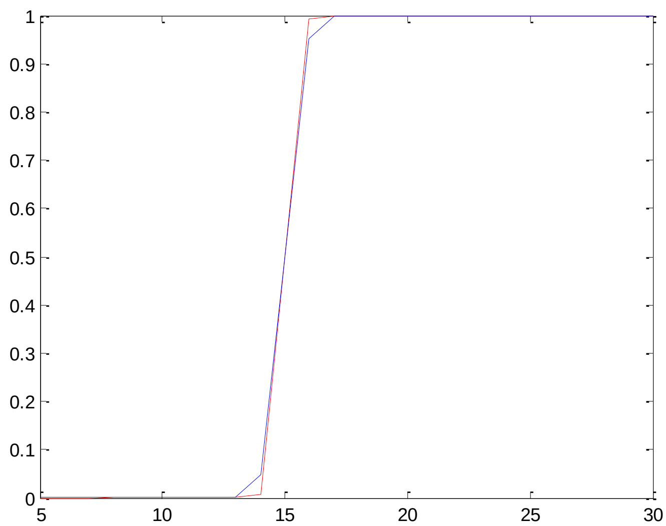


Fig. 3. Evaluation of 'x is greater than 15' using a sigmoid (c=3 blue, c=5 red)

Similarly, the statement ***x is less than 15*** is evaluated by using the piecewise continuous function

$$f(x) = \begin{cases} \dfrac{1}{1+(15-x)^{-2}}, & x < 15 \\ 0, & x \geq 15 \end{cases} \qquad \textbf{Eq. (4)}$$

or the relatively sharp sigmoid

$$f(x) = \frac{1}{1+e^{c(x-15)}}, \quad c > 1 \qquad \textbf{Eq. (5)}$$

Statements like ***x is low***, ***x is high***, ***x is medium*** is very easy to be evaluated by simply using proper gausians centered at the values we consider low, high or medium respectively. Alternatively, we may use triangular or trapezoidal functions but these are piece-wise continuous and therefore we should be careful when differentiating around the points of discontinuities.

<u>2nd step. Fuzzy Inference and defuzzification</u>

Let's take a look to the following figure 4.

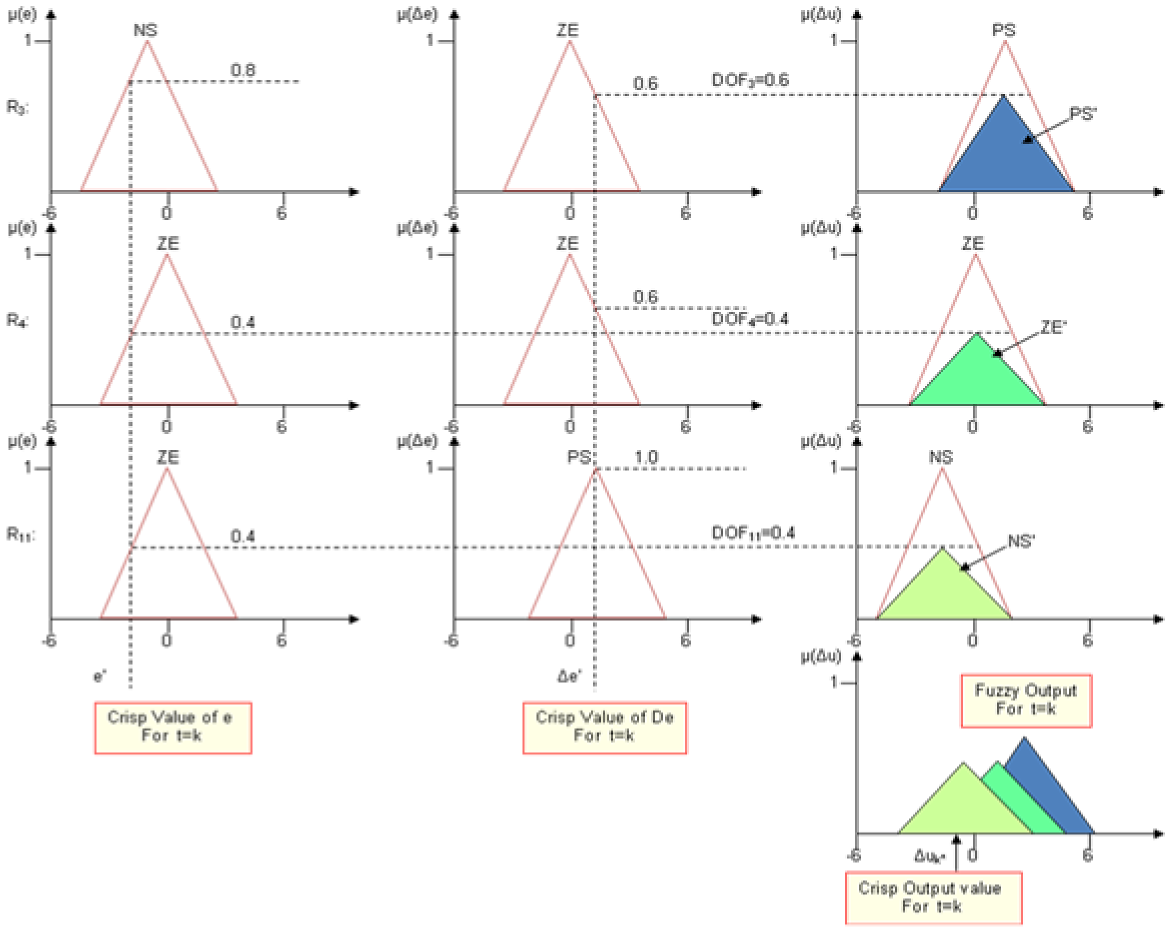


Fig. 4. Fuzzy inference and defuzzification procedure

It represents 3 activated fuzzy linguistic rules each one being of the form

IF e is fuzzy value and Δe is fuzzy value then Δu is fuzzy value

where, depending on the variable, ***fuzzy value*** may assume the values NS, ZE, PS, etc. In this figure, in the fuzzy inference procedure we assume that each rule connecting only one antecedent with one consequent can be represented by a fuzzy relation, which is constructed using the Larsen's product implication operator. Next using max-min synthesis of the fuzzy singleton (representing the measurement) with the fuzzy relation a downsized triangle will appear in the output fuzzy variable (THEN part). The degree of downsizing is determined by the firing strength (DOF) of the rule. In case we have the connection of 2 simple rules in one using the AND connective the downsizing is given by the ***min*** of the two DOFs or the ***product*** of the two DOFs. In Fig. 4, each rule is complex (the connection of 2 simple ones) and the DOF of each rule is the ***min*** of the respective two DOFs. **For our purpose** we prefer to use the ***product*** of the DOFs. If we judge that the product lowers the DOF too much we could adopt some intermediate combination, provided that this results in a differentiable function.

Now, it's time to introduce some notations.

We assume that the output variable has M fuzzy values, each one being represented by a membership function having a pick at $o_l, \quad l=1 \ldots M$. (keep in mind that we prefer to have membership function with a pick. Alternatives have to be treated differently)

We assume that the number of input variables are N. Let also that the input membership functions are denoted by $f_i^l(x_i), \quad i=1,\ldots N \quad l=1,\ldots M$. Here the notation means that we have a membership function that concerns the i^{th} input and affects the l^{th} output membership function. Therefore, the DOF affecting the l^{th} output membership function is given by

$DOF^l = \min(f_1^l(x_1), f_2^l(x_2), \ldots f_N^l(x_N))$ if the MIN is used to interpret the AND connective.

$DOF^l = \prod_{i=1}^N f_i^l(x_i)$ if the PRODUCT is used to interpret the AND connective.

Now, in order to defuzify the output and get a crisp value we may use center average defuzifier and take into account all output membership functions produced by every rule. In this case the crisp value is given by

$$F(x) = \frac{\sum_{l=1}^{M} o_l \left(\prod_{i=1}^{N} f_i^l(x_i) \right)}{\sum_{l=1}^{M} \left(\prod_{i=1}^{N} f_i^l(x_i) \right)} \qquad \textbf{Eq. (6)}$$

The above functional represents the crisp output of the entire set of fuzzy rules. Normally this output is to be used as one of the control signals $u_j, \quad j=1 \ldots r$. We may have one such function $F_j(x)$ for each control signal.

3rd step. Writing down the constraint

Following the above analysis, having in mind the entire set of rules, the constraint involving the states x and the output u_j might be of the form

$u_j - F_j(x) = 0$ **Eq. (7)**

or alternatively

$u_j - F_j(x) > -\delta, \quad u_j - F_j(x) < \delta, \quad \delta > 0 \; and\, small$ **Eq. (8)**

This way we may have a number *r* of constraints.

Skipping into more details

1) The connective of the antecedent variables is the **OR**. In this case the total DOF of the rule could be the ***max*** of the DOFs. However, this is not desirable (max is not good for differentiation). To resolve this there are two alternatives. One is to use two or more separate rules, each one containing each antecedent variable (all rules point to the same output membership function). The other alternative is to use a differentiable function resembling the action of ***max.***

For example, if we have two binary numbers a,b then $a+b-ab$ will produce the maximum of them. This formula does not produce any problems in differentiation but if the numbers are between 0 and 1 will usually give something that is larger than the maximum. We could probably seek for an alternative producing a result closer to the maximum value. Let's consider the function

$$\frac{a+b-2.2(ab)}{1-1.2(ab)}$$ **Eq. (9)**

Testing various numbers (*a*,*b*) in the range of 0...1 we can verify that this formula gives a result close to ***max*** (*a*,*b*). Moreover, if any or both of *a*,*b* are either 0 or 1 it will produce exactly the maximum (try it). WARNING. THE FORMULA IS NOT CONSISTENT IN ALL VALUE COMBINATIONS.

A similar approach can be followed if we want to replace the PRODUCT with something different in performing the AND connective.

2) How to treat rules where the consequent is difficult to be expressed with membership functions that are not symmetric and do not present a pick.

Let's examine the rule

IF variable1 >< value1 AND/OR variable2 >< value2 THEN ***increase***/***decrease*** a control value

In this case we could probably implement this rule by constructing two mbfs, one for ***increase*** and the other for ***decrease***. They could be associated with degrees of increase/decrease (in the x axis) and could be also complemented by a mbf which says 'do nothing'. In this case increase and decrease can be either one-sided Gaussians or one-sided triangles. 'do nothing' can be a symmetric Gaussian or triangle. This implementation means also that we have to rewrite the rules appropriately.

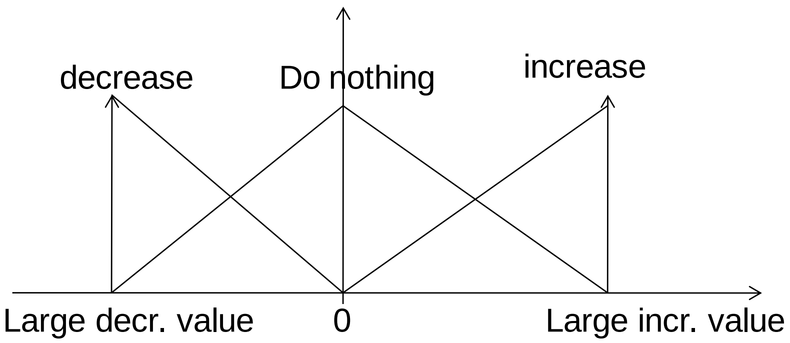


Fig. 5. Mbfs for increase-decrease-do nothing actions

Another rule case is the one that in the THEN part contains ON/OFF actions (e.g. start heating, Lights ON, Lights OFFF, turn ON blinds etc). One solution to this difficult case is to construct two mbfs (one for OFF, one for ON), which are one sided triangles (facing one against the other - one common point in the middle) and then take the ***largest of maximum*** aggregation.

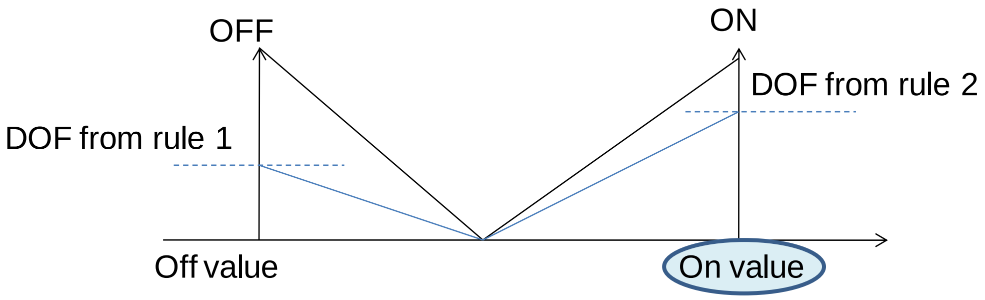


Fig. 6 Mbfs forON-OFF actions

Now, assuming on value = 1 and off value = 0 we could probably use a sharp sigmoid around 0 to evaluate the difference (DOF2-DOF1) in respect to 0 and get the winning On (~1) or Off (~0) value. This way we may get ON(~1) if DOF2 > DOF1 with a noticeable difference. The sigmoid below, with various inclinations demonstrates its use. It should be noticed that this approach "favors" the OFF value in the sense that if the difference is not noticeable (or if DOF1 > DOF2) the OFF value (~0) is preferred.

In this case the crisp output is

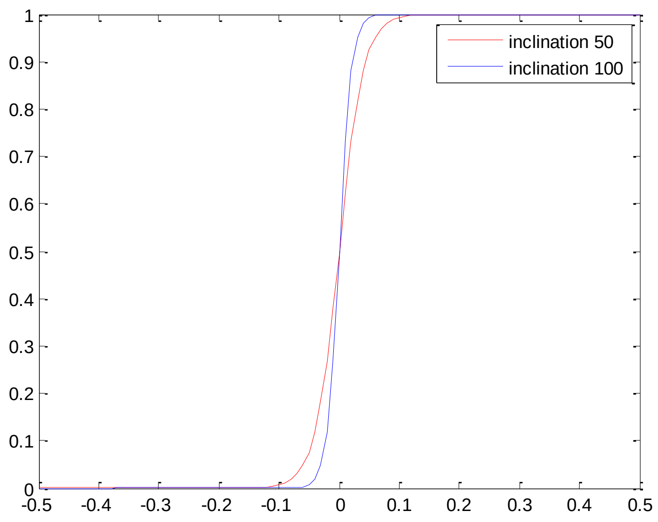
$$F(x) = \frac{1}{1 + e^{-C\left[\prod_{i=1}^{N} f_i^2(x_i) - \prod_{i=1}^{N} f_i^1(x_i)\right]}}, \quad C\ large \qquad \textbf{Eq. (10)}$$

and the arising condition

$$u_j - F_j(x) = 0 \qquad \textbf{Eq. (11)}$$

or alternatively

$$u_j - F_j(x) > -\delta, \quad u_j - F_j(x) < \delta, \quad \delta > 0\ and\ small \qquad \textbf{Eq. (12)}$$



Applying the described procedure in various types of rules

Example 1. (ZUB building)

(open-close window rules)

R1: IF *room temp* > 24 AND *outside temp* <= 23 AND *room air quality* > 600 AND *wind speed* <= 10 THEN *open window*

R2: IF *room temp* < 21 AND *outside temp* >= 22 AND *room air quality* > 600 AND *wind speed* <= 10 THEN *open window*

R3: IF *room humidity* > 60% AND *outside air moisture* = *low* THEN *open window*

R4: IF *room humidity* < 40% AND *outside air moisture* = *high* THEN *open window*

R5: IF *wind speed* >= 10 THEN *close window*

We proceed as follows.

Rule 1

Let f_1^1 be the evaluation function for the condition *room temp* > 24. Here the upper index of f denotes the rule and the lower denotes its order of appearance in the rule. f_1^1 is selected to be of the form of eq. (3). That is $f_1^1(x_1) = \frac{1}{1+e^{-c(x_1-24)}}$, $c > 1$, where x1= room temp.

Let f_2^1 be the evaluation function for the condition *outside temp* <= 23. f_2^1 is selected to be of the form of eq. (5). That is $f_2^1(x_2) = \frac{1}{1+e^{c(x_2-23)}}$, $c > 1$, where x2= outside temp

Similarly for room air quality we use $f_3^1(x_3) = \frac{1}{1+e^{-c(x_3-600)}}$, $c > 1$

And for wind speed we use $f_4^1(x_4) = \frac{1}{1+e^{c(x_4-10)}}$, $c > 1$

Since all statements of the rule are connected with the AND connective the firing strength (Degree of Fulfillment – DOF) of the rule may be evaluated by the min operator or alternatively by the product operator.

That is, $DOF^1 = \prod_{i=1}^{4} f_i^1(x_i)$ **Eq. (13)**

Rule 2: IF *room temp* < 21 AND *outside temp* >= 22 AND *room air quality* > 600 AND *wind speed* <= 10 THEN *open window*

Now $DOF^2 = \prod_{i=1}^{4} f_i^2(x_i)$, **Eq. (14)**

Where $f_1^2(x_1) = \frac{1}{1+e^{c(x_1-21)}}$, $f_2^2(x_2) = \frac{1}{1+e^{-c(x_2-22)}}$, $f_3^2(x_3) = \frac{1}{1+e^{-c(x_3-600)}}$, $f_4^2(x_4) = \frac{1}{1+e^{c(x_4-10)}}$

Rule 3: IF *room humidity* > 60% AND *outside air moisture* = *low* THEN *open window*

Now $DOF^3 = \prod_{i=5}^{6} f_i^3(x_i)$, **Eq. (15)**

where x5 = room humidity and x6 = moisture

and $f_5^3(x_5) = \frac{1}{1+e^{-c(x_5-60)}}$, $f_6^3(x_6) = e^{-c(x_6-L)^2}$ (a one-sided Gaussian centered at L, where L is the minimum measurement)

Rule 4: IF *room humidity* < 40% AND *outside air moisture* = *high* THEN *open window*

Now $DOF^4 = \prod_{i=5}^{6} f_i^4(x_i)$, **Eq. (16)**

where x5 = room humidity and x6 = moisture

and $f_5^4(x_5) = \frac{1}{1+e^{c(x_5-40)}}$, $f_6^4(x_6) = e^{-c(x_6-H)^2}$ (a one-sided Gaussian centered at H, where H is the maximum measurement)

SO FAR, ALL 4 RULES CONTRIBUTE TO *open window*. Therefore, we have to take the effect of all rules in open window action. Since these rules are connected with the OR connective the DOF of the open window action (see for example figure 6 for its shape) will be

$DOF_{OW} = \max_{r=1}^{4}(DOF^r)$ **Eq. (17)**

But we do not want to use max instead we use the approximate formula (which however is enough for our purposes)

Max(a,b) = a+b-ab

Max(a,b,c) = a+b+c+abc-ab-ac-bc

Max(a,b,c,d) = a+b+c+d+abc-ab-ac-bc-ad-bd-cd-abcd+abd+acd+bcd **Eq. (18)**

RULE 5 IS THE ONLY ONE THAT DIRECTLY CONTRIBUTES TO "*close window*".

Rule 5: IF *wind speed* >= 10 THEN *close window*

In this case $DOF_{CW} = \frac{1}{1+e^{-c(x_5-10)}}$ **Eq. (19)**

NEXT FOLLOWING A RATIONALE SIMILAR TO THE EXTRACTION of Eq. (12) we conclude that the control value (near to 0 for close or near to 1 for open) will be given by

$$F(x) = \frac{1}{1+e^{-C[DOF_{OW} - DOF_{CW}]}}, \quad C\ large$$ **Eq. (20)**

And the conditions are

$$u - F(x) > -\delta, \quad u - F(x) < \delta, \quad \delta > 0\ and\ small$$

FINAL REMARK: The final functional (eq. 20) may appear complicated and perhaps frightens a bit. Take however into account that logsig has a straightforward derivative [f*(1-f)] and the various terms in DOFow and DOFcw are either sigmoids of one state only or sum of products of such sigmoids. With some elaboration exact analytical formulas can be derived.

****

Take for example eq. (20) and let's try to find the derivative of F(x) in respect to x1.

$$\frac{\partial F(x)}{\partial x_1} = \frac{\partial F(x)}{\partial s}\frac{\partial s}{\partial x_1} = CF(s)[1-F(s)]\frac{\partial s}{\partial x_1}, \quad s = DOF_{OW} - DOF_{CW}$$

But $\frac{\partial s}{\partial x_1} = \frac{\partial\, DOF_{OW}}{\partial x_1}$ and DOF_{OW} is computed using eq. (18). In this equation a= $DOF^1 = \prod_{i=1}^4 f_i^1(x_i)$,

b = $DOF^2 = \prod_{i=1}^4 f_i^2(x_i)$, c = $DOF^3 = \prod_{i=5}^6 f_i^3(x_i)$, d = $DOF^4 = \prod_{i=5}^6 f_i^4(x_i)$

Therefore x_1 appears in eq. (18) only in the terms that contain a and b. That is,

$$\frac{\partial s}{\partial x_1} = \frac{\partial}{\partial x_1}\left[a + b + abc - ab - ac - bc - ad - bd - abcd + abd + acd + bcd\right]$$

Let's see each term separately

$$\frac{\partial a}{\partial x_1} = \frac{\partial}{\partial x_1}\left(\prod_{i=1}^4 f_i^1(x_i)\right) = \frac{\partial f_1^1(x_1)}{\partial x_1}\prod_{i=2}^4 f_i^1(x_i) = cf_1^1(x_1)\left(1 - f_1^1(x_1)\right)\prod_{i=2}^4 f_i^1(x_i)$$

$$\frac{\partial b}{\partial x_1} = \frac{\partial}{\partial x_1}\left(\prod_{i=1}^4 f_i^2(x_i)\right) = \frac{\partial f_1^2(x_1)}{\partial x_1}\prod_{i=2}^4 f_i^2(x_i) = -cf_1^2(x_1)\left(1 - f_1^2(x_1)\right)\prod_{i=2}^4 f_i^2(x_i)$$ Here the sign of *c* changes.

$$\frac{\partial ab}{\partial x_1} = \frac{\partial a}{\partial x_1}b + \frac{\partial b}{\partial x_1}a = \frac{\partial f_1^1(x_1)}{\partial x_1}\prod_{i=2}^4 f_i^1(x_i)\prod_{i=1}^4 f_i^2(x_i) + \frac{\partial f_1^2(x_1)}{\partial x_1}\prod_{i=2}^4 f_i^2(x_i)\prod_{i=1}^4 f_i^1(x_i)$$

$$\frac{\partial abc}{\partial x_1}=\frac{\partial a}{\partial x_1}bc+\frac{\partial b}{\partial x_1}ac=\frac{\partial f_1^1(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^1(x_i)\prod_{i=1}^{4}f_i^2(x_i)\prod_{i=5}^{6}f_i^3(x_i)+$$
$$+\frac{\partial f_1^2(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^2(x_i)\prod_{i=1}^{4}f_i^1(x_i)\prod_{i=5}^{6}f_i^3(x_i)$$

$$\frac{\partial ac}{\partial x_1}=\frac{\partial}{\partial x_1}\left(\prod_{i=1}^{4}f_i^1(x_i)\right)\prod_{i=5}^{6}f_i^3(x_i)=\frac{\partial f_1^1(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^1(x_i)\prod_{i=5}^{6}f_i^3(x_i)$$

$$\frac{\partial ad}{\partial x_1}=\frac{\partial}{\partial x_1}\left(\prod_{i=1}^{4}f_i^1(x_i)\right)\prod_{i=5}^{6}f_i^4(x_i)=\frac{\partial f_1^1(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^1(x_i)\prod_{i=5}^{6}f_i^4(x_i)$$

$$\frac{\partial bc}{\partial x_1}=\frac{\partial}{\partial x_1}\left(\prod_{i=1}^{4}f_i^2(x_i)\right)\prod_{i=5}^{6}f_i^3(x_i)=\frac{\partial f_1^2(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^2(x_i)\prod_{i=5}^{6}f_i^3(x_i)$$

$$\frac{\partial bd}{\partial x_1}=\frac{\partial}{\partial x_1}\left(\prod_{i=1}^{4}f_i^2(x_i)\right)\prod_{i=5}^{6}f_i^4(x_i)=\frac{\partial f_1^2(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^2(x_i)\prod_{i=5}^{6}f_i^4(x_i)$$

$$\frac{\partial abd}{\partial x_1}=\frac{\partial a}{\partial x_1}bd+\frac{\partial b}{\partial x_1}ad=\frac{\partial f_1^1(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^1(x_i)\prod_{i=1}^{4}f_i^2(x_i)\prod_{i=5}^{6}f_i^4(x_i)+$$
$$+\frac{\partial f_1^2(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^2(x_i)\prod_{i=1}^{4}f_i^1(x_i)\prod_{i=5}^{6}f_i^4(x_i)$$

$$\frac{\partial acd}{\partial x_1}=\frac{\partial}{\partial x_1}\left(\prod_{i=1}^{4}f_i^1(x_i)\right)\prod_{i=5}^{6}f_i^3(x_i)\prod_{i=5}^{6}f_i^4(x_i)=\frac{\partial f_1^1(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^1(x_i)\prod_{i=5}^{6}f_i^3(x_i)\prod_{i=5}^{6}f_i^4(x_i)$$

$$\frac{\partial bcd}{\partial x_1}=\frac{\partial}{\partial x_1}\left(\prod_{i=1}^{4}f_i^2(x_i)\right)\prod_{i=5}^{6}f_i^3(x_i)\prod_{i=5}^{6}f_i^4(x_i)=\frac{\partial f_1^2(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^2(x_i)\prod_{i=5}^{6}f_i^3(x_i)\prod_{i=5}^{6}f_i^4(x_i)$$

$$\frac{\partial abcd}{\partial x_1}=\frac{\partial a}{\partial x_1}bcd+\frac{\partial b}{\partial x_1}acd=\frac{\partial f_1^1(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^1(x_i)\prod_{i=1}^{4}f_i^2(x_i)\prod_{i=5}^{6}f_i^3(x_i)\prod_{i=5}^{6}f_i^4(x_i)+$$
$$+\frac{\partial f_1^2(x_1)}{\partial x_1}\prod_{i=2}^{4}f_i^2(x_i)\prod_{i=1}^{4}f_i^1(x_i)\prod_{i=5}^{6}f_i^3(x_i)\prod_{i=5}^{6}f_i^4(x_i)$$

Remark: Terms that contain products of DOFS (that is products of sigmoidals) of rules that are conflicting they do not practically contribute anything significant because in this case one of the products is practically zero and drags down to zero the entire product. Therefore, the above formulas are too analytic and can be simplified if such information is taken into account. In our example terms containing the product *a.b* will be practically zero because *a* and *b* are related to Rules 1 and 2, which cannot be fulfilled at the same time.

Example 2. (Crete Urban network)

(rules increasing-decreasing a variable or system parameter)

Before starting we have to make a distinction. If the quantity that increases or decreases is a system parameter then we do not need to be concerned with it within the ConvCD approach. It can be performed externally and contribute to the system variation, which (system) is considered "unknown" and estimated on-line. But if the quantity is a state or control variable then we will apply the procedure described below in order to get the constraints.

We observe that in the Urban network the rules need some improvement in order to be logically complete. Let's see one set of rules (Cycle control rules)

Rule 1: IF *Region (capacity)* > 90% OR *50% junctions (capacity)* > 90% THEN *Increase cycle*

Rule 2: IF *Region (capacity)* < 60% THEN *Decrease cycle*

We complement these two rules with

Rule 3: IF *Region (capacity)* < 90% AND *Region (capacity)* > 60% AND *50% junctions (capacity)* < 90% THEN *Do nothing*

We use Fig. 5 to represent increase, decrease and do nothing membership functions. We assume that the increase or decrease predefined step corresponds to the Large increase (LIV) or decrease (LDV) values of the figure. Similarly, zero is the largest do nothing value (DNV). This way, in case we have rules that are partially fulfilled the result will be an increase or decrease value that is a portion of the predefined step (weak increase or decrease action). Let's follow the implementation

Rule 1: IF *Region (capacity)* > 90% OR *50% junctions (capacity)* > 90% THEN *Increase cycle*

It is the only rule that contributes to the increase cycle action

Let f_1^1 be the evaluation function for the condition *Region (capacity)* > 90%. Here the upper index of f denotes the rule and the lower denotes its order of appearance in the rule. f_1^1 is selected to be of the form of eq. (3). That is $f_1^1(x_1) = \frac{1}{1+e^{-c(x_1-90)}}$, $c > 1$, where x1= Region (capacity).

Let f_2^1 be the evaluation function for the condition *junctions (capacity)* > 90%. f_2^1 is selected to be of the form of eq. (3). That is $f_2^1(x_2) = \frac{1}{1+e^{-c(x_2-90)}}$, $c > 1$, where x2= junctions (capacity)

Since the connective is the OR we will implement it using the max operator. Therefore the firing strength (degree of fulfillment) of the rule is computed by

$$DOF^1 = f_1^1(x_1) + f_2^1(x_2) - f_1^1(x_1) f_2^1(x_2) \qquad \textbf{eq. (21)}$$

Rule 2: IF *Region (capacity)* < 60% THEN *Decrease cycle*

Here DOF is simply

$$DOF^2 = f_1^2(x_1) \qquad \textbf{eq. (22)}$$

Where $f_1^2(x_1) = \frac{1}{1+e^{c(x_1-60)}}$, $c > 1$

Rule 3: IF *Region (capacity)* < 90% AND *Region (capacity)* > 60% AND *50% junctions (capacity)* < 90% THEN *Do nothing*

Here, since we have the AND connective, DOF is given by

$$DOF^3 = f_1^3(x_1)\, f_2^3(x_1)\, f_3^3(x_2) \qquad \textbf{eq. (23)}$$

Where $f_1^3(x_1) = \dfrac{1}{1+e^{c(x_1-90)}}$, $f_2^3(x_1) = \dfrac{1}{1+e^{-c(x_1-60)}}$, $f_3^3(x_2) = \dfrac{1}{1+e^{c(x_1-90)}}$, $c>1$

Using standard fuzzy inference procedure the final crisp outcome (after defuzzification) is computed using similar rationale with the derivation of eq. (6) and is

$$F(x) = \frac{LIV * DOF^1 + LDV * DOF^2 + DNV * DOF^3}{\sum_{l=1}^{3} DOF^l} =$$

$$= \frac{LIV * \left(f_1^1(x_1) + f_2^1(x_2) - f_1^1(x_1)\, f_2^1(x_2) \right) + LDV * f_1^2(x_1) + DNV * \left(f_1^3(x_1)\, f_2^3(x_1)\, f_3^3(x_2) \right)}{f_1^1(x_1) + f_2^1(x_2) - f_1^1(x_1)\, f_2^1(x_2) + f_1^2(x_1) + f_1^3(x_1)\, f_2^3(x_1)\, f_3^3(x_2)}$$

But DNV is in our case zero and therefore

$$F(x) = \frac{LIV * \left(f_1^1(x_1) + f_2^1(x_2) - f_1^1(x_1)\, f_2^1(x_2) \right) + LDV * f_1^2(x_1)}{f_1^1(x_1) + f_2^1(x_2) - f_1^1(x_1)\, f_2^1(x_2) + f_1^2(x_1) + f_1^3(x_1)\, f_2^3(x_1)\, f_3^3(x_2)} = \frac{F_N(x)}{F_D(x)} \qquad \textbf{eq. (24)}$$

And the derived conditions are

$u - F(x) > -\delta, \quad u - F(x) < \delta, \quad \delta > 0 \; and\, small$, where u is the increase/decrease variable.

The partial derivatives of F(x) are easy to be obtained. Let's see for example $\dfrac{\partial F}{\partial x_1}$

$$\frac{\partial F}{\partial x_1} = \frac{\dfrac{\partial F_N(x)}{\partial x_1} F_D(x) - \dfrac{\partial F_D(x)}{\partial x_1} F_N(x)}{\left(F_D(x)\right)^2}, \text{ where}$$

$$\frac{\partial F_N(x)}{\partial x_1} = LIV * \left(\frac{\partial f_1^1(x_1)}{\partial x_1} - \frac{\partial f_1^1(x_1)}{\partial x_1} f_2^1(x_2) \right) + LDV * \frac{\partial f_1^2(x_1)}{\partial x_1} =$$

$$= c\, LIV\; f_1^1(x_1)\left(1 - f_1^1(x_1)\right)\left[1 - f_2^1(x_2)\right] - c\, LDV f_1^2(x_1)\left(1 - f_1^2(x_1)\right)$$

$$\frac{\partial F_D(x)}{\partial x_1} = \frac{\partial f_1^1(x_1)}{\partial x_1} - \frac{\partial f_1^1(x_1)}{\partial x_1} f_2^1(x_2) + \frac{\partial f_1^2(x_1)}{\partial x_1} + \frac{\partial f_1^3(x_1)}{\partial x_1} f_2^3(x_1)\, f_3^3(x_2) + \frac{\partial f_2^3(x_1)}{\partial x_1} f_1^3(x_1)\, f_3^3(x_2)$$

$$= c\; f_1^1(x_1)\left(1 - f_1^1(x_1)\right)\left[1 - f_2^1(x_2)\right] - c\; f_1^2(x_1)\left(1 - f_1^2(x_1)\right)$$

$$-c\; f_1^3(x_1)\left(1 - f_1^3(x_1)\right) f_2^3(x_1)\, f_3^3(x_2) + c\; f_2^3(x_1)\left(1 - f_2^3(x_1)\right) f_1^3(x_1)\, f_3^3(x_2)$$

6 External user groups

In this chapter, different LSCS providers and operators covering many ERTI sectors are contacted in order to analyze the needs and views of these SCADA/DCSs. The external user group members have been asked to provide – through either personal interviews or questionnaires their views on existing LSCSs and SCADA/DCSs. Moreover, members of the group will be invited to consortium meetings. Finally, the external user group will get privileged access to information about the project's progress and results. At this stage of the project the members of the external user group correspond to people with close connections to the AGILE partners. The external user group will be enhanced with more members at later stages of the project.

Application Area	**Urban traffic control system**			
Briefly Description related to AGILE	Calculate "optimal" network-wide signal control settings. Minimize system total delays, increase the capacity of the system, reduce the queues of the network, balance the queues of the network in order to avoid spillovers and gridlocks			
Sensor measurement used	Traffic flow, occupancy, speed, CO2, meteorological sensors			
Actions	Traffic lights plans			
Person contact details	Name	Title	Phone	Email
	Félix Lerma	Mobility department manager (Sevilla Council)	+ 0034 606626163	Obras.proyectos@sevilla.org
	José Manuel Gómez Revuelta	Mobility department manager (Santander Council)	+ 0034 942200656	ingindustrial@ayto-santander.es

Application Area	**Interurban traffic control system**			
Briefly Description related to AGILE	Control of the traffic levels in a motorway, controlling a large section of the road			
Sensor measurement used	Traffic flow, occupancy, speed, CO2, wind sensors			
Actions	Visual Message Signs (VMS) with Variable Speed Limits (VSL), incidents or meteorological information, ramp metering			
Person contact details	Name	Title	Phone	Email
	Adolfo Mozota	DGT (Traffic General Direction) Zaragoza Council		mozota@dgt.es

		manager		

Application Area	Air Pollution Monitoring Systems			
Briefly Description related to AGILE	Basically it is a system for acquiring and monitoring. There are not action issues directly in the Air Pollution Monitoring System that feed the system.			
Sensor measurement used	Level of particulates in the air (ozone level,…)			
Actions	SMS to authorities, information to the citizens (website, message signs,…), traffic systems (prevent the congestion in an area),…			
Person contact details	Name	Title	Phone	Email
	Ana Lacasa	Servicio Protección a la Atmósfera (Madrid Council)	+ 0034 91480066	contaminacion@madrid.es

Application Area	Interchange Station Systems / Train Station			
Briefly Description related to AGILE	Various types of elements with few dependencies among them related to security, traffic management in the station and support (lifts, stairs, phones, directional CCTV, access barrier, panels, blinds, …).			
Sensor measurement used	Access detectors (microwaves, temperature, infrared, magnets), level of particulates in the air, automatic number plate recognition, …			
Actions	Switch on/off lighting systems, lifts, doors, CCTVs (also directional movements), climate control, …			
Person contact details	Name	Title	Phone	Email
	Dionisio González	Madrid interchange station manager	+ 0034 609 656 036	dionisio.gonzalez@ctm-comadrid.com

Application Area	Tunnel Security Systems
Briefly Description related to AGILE	Elements related to security (CCTV, access barrier, atmosphere control,…) with limited actions.
Sensor measurement used	Level of particulates in the air (ozone level, carbon monoxide, nitric oxide, nitrogen dioxide, …), visibility (fog, smoke, …), air velocity/direction, photometer, Height Detector …
Actions	Switch on/off lighting systems, access barriers, CCTVs (also directional movements), atmosphere control, radio RDS information, …

Person contact details	Name	Title	Phone	Email
	Adolfo Mozota	DGT (Traffic General Direction) Zaragoza Council manager		mozota@dgt.es

Application Area	**Water Management**			
Briefly Description related to AGILE	The main issue is to long term supply drinking water supplement, continuously and consider processes and constraints. Outputs from the water resource management process should include: - Water resources usage – scheduling, quantity and replacements from each resource to another - Water allocation approvals according their supplement capability Water quality approval – at each resource and infrastructure			
Sensor measurement used	- Flow type: Max Flow, Flow type, - Quality: Turbidity, Salinity, Mineral, - Blue-green algae, Noxious weeds			
Actions	Adjust resources sluice-gates			
Person contact details	Name	Title	Phone	Email
	Prof' Uri Marchaim	Head, Dept of Biotechnology, Dept of Regional Development, MIGAL - Galilee Technology Center	+972 4 6953596	uri@migal.org.il
	José Adolfo Alvarez	Confederación Hidrográfica del Ebro responsible	+ 0034 976 71 12 06	JAAlvarez@chebro.org
	José Antonio Hinojal	Confederación Hidrográfica del Tajo responsible	+ 0034 91 453 96 99	joseantonio.hinojal@chtajo.es

Application Area	**Big Campus Energy controlling**
Briefly Description related to AGILE	Energy controlling very big campuses as airport terminals for efficiency A/C, humidity and luminance in the halls and corridors,

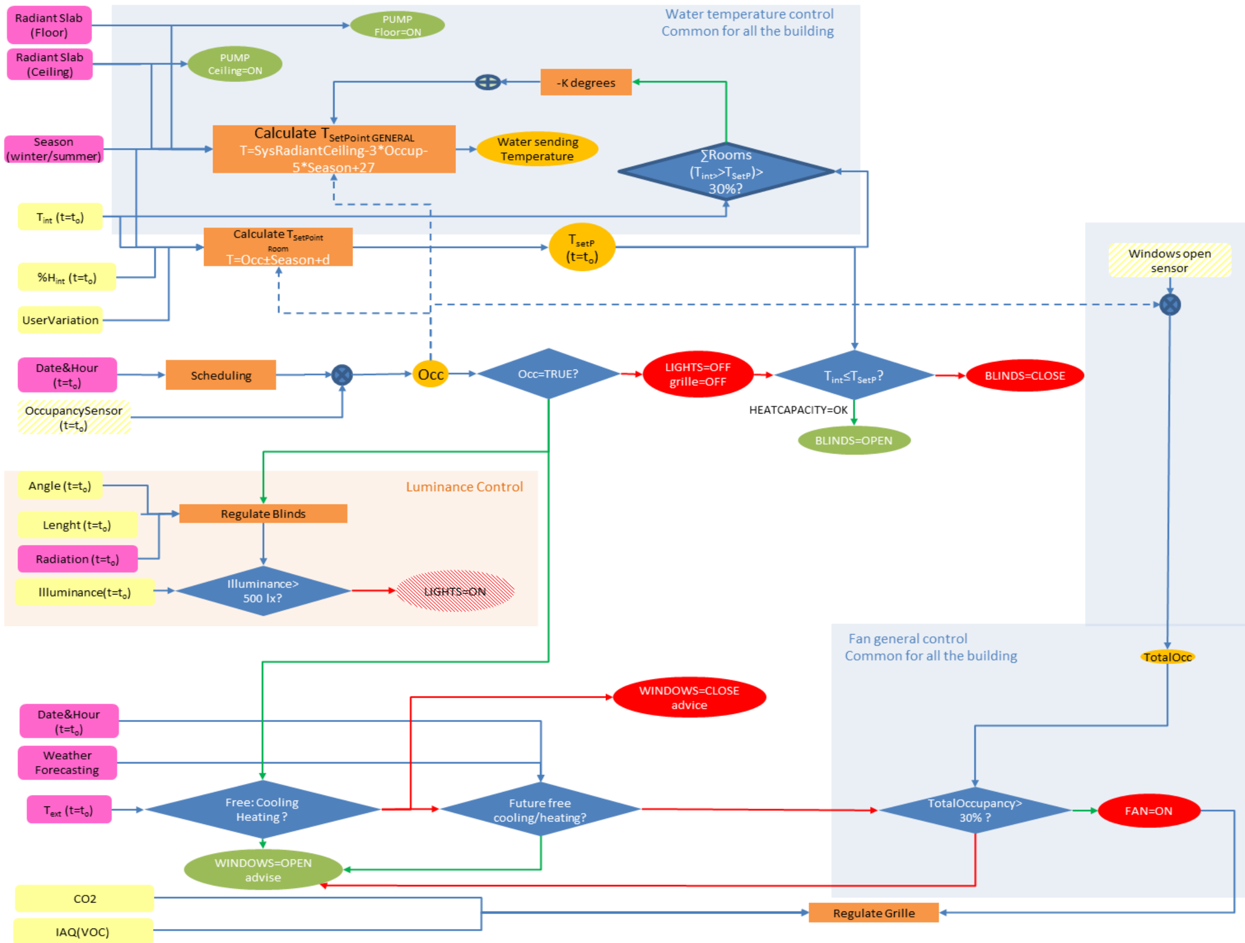
	when the occupancy is unknown and may extremely varies.			
Sensor measurement used	Temperature sensors installed in dedicated places, humidity and illumination sensors, CO2 sensors, outdoor weather measurement sensors (rain, wind speed, temperature).			
Actions	Heating/cooling according the occupancies and the measured humidity. The activator may open windows to fresh air when possible or when CO2 level measured is too high.			
Person contact details	Name	Title	Phone	Email
	Mr. Meir Saggie	Advisor	+ 972 52 2365348	Meir.saggie@gmail.com

Application Area	**Controlling sewage systems**			
Briefly Description related to AGILE	Big and complex systems that should deals with unexpected sewage water coming from multiple sources, where their internal compound is unknown			
Sensor measurement used	Several types – flowed sensor, turbidity sensor, chemical, metals detectors			
Actions	Handling decisions how to clean the sewage, while needed to blending several chemicals liquids decisions on their amount is required.			
Person contact details	Name	Title	Phone	Email
	Dr. George Chamilothoris	Prof., expert in SCADA systems for sewage systems and networks	+30-210-538-1427	thor@teipir.gr

7 ANNEX 1: RULE-BASED CONTROL SYSTEM (smart building)

The following annex will describe the total control of the building divided in two different categories, the controls belonging to the single zones (individual/room controls) and those that are implemented over systems that control the complete building (general variables)

It is also based on PEBBEL project, which is a leading project (funded by FP7) to measure and control the smart building and traffic.



The flow diagram describes the open window process of the smart building.

In order to understand the complete design are going to be defined:

1. General variables of the system: They will be common for the complete building.
   a. Radiant Floor [Yes/No]: Distribution of heating/cooling through the floors.
   b. Radiant Ceiling [Yes/No]: Distribution of heating/cooling through the ceilings.
   c. Season [Winter/Summer]: Common definition for the building, supposing that the building will be all heated or cooled at the same time.
   d. Date/Hour : Needed to define the solar angles, and the scheduling
   e. Radiation: Measured mainly on the horizontal surface in two different ways (Total/diffuse)
   f. External temperature: Dry temperature. External humidity and pressure variables could be useful to control the building although nowadays no humidity control is implemented.
   g. Weather forecast: Needed to decide the possible opening or close of the windows during the night/weekend.

2. Particular Variables of each controlled zone: Measured internally the rooms. It will be one of them for each zone.
   a. Instantaneous Dry Temperature of the controller installed in each zone.
   b. Instantaneous humidity of each zone (relative or absolute)
   c. User variation of the pre-set temperature set points
   d. Sensor that control the window opening.
   e. Last blind angle stored (last angular position)
   f. Last blind position stored (last longitudinal position)
   g. Zone luminance
   h. CO2 sensor
   i. IAQ sensor

   Note: There are two rooms and a meeting room with other different temperature sensors.

3. Intermediate Calculations :
   a. Sending temperature to Radiant Ceiling/Floor:
   b. Variation of the sending temperature
   c. Calculation of the internal setpoint
   d. Scheduling
   e. Blind regulation
   f. Grille regulation

4. Calculation Result :
   a. Water Distribution Sending temperature
   b. Internal Temperature Set point

c. Occupancy : Occupancy of a single zone
d. Total Occupancy: Occupancy of a single zone with the windows closed.

5. Positive Action :

a. Pump Floor On
b. Pump Ceiling On
c. Blinds open
d. Lights On
e. Windows open (Advice)

6. Negative Action :

a. Lights Off
b. Grilles Off
c. Blinds close
d. Windows close (Advice)
e. Fan On

7. If

8. Blue Darts: → Signal Input.
9. Green Darts: → “Yes” Case.
10. Red Darts: → “No” Case.

11. Blue Shadowed zone: General control of the building. Everything inside control common variables for the zones.

a. Fan (On/Off)
b. Water Sending Temperature (Common for the building)

12. Orange Shadowed zone: Luminance control independent for each zone.

13. No Shadowed zone: Zone control of each zone. (It must be programmed n-times)

Philosophy to understand the control of the complete building:

About the general control of the system is important to underline the next points for a complete understanding of the general building operation. Physical systems installed in the building establish that some parameters have priority over the others for the building.

1. **Water temperature general control:** Both **radiant systems in each room depend on the activation of the general pump** that deliver the fluid to each zone circuit, so the" all building ceiling pump" and "all building floor pump" will be activated by the concept of season and the needed of one or the other system to obtain different research objectives.
2. **Each hydraulic room circuit does NOT have the possibility to choose the incoming temperature to the rooms**, so the general sending temperature to the building must provide the water with enough energy to deliver the demanded heat. (In the cooling case, the energy provided by the ground slabs is smaller than the one needed by the complete building, so there will be no control on the sending temperature)
3. **Fan general control:** The air delivery to the occupied zones is nowadays controlled by a scheduling increasing the speed with a pressure drop sensor, independently of the occupancy of the zones.
    a. There is a priority of air delivering to the meeting rooms over the offices (the air treated is not enough for both spaces. (That is already in the currently system programmed)
    b. We have developed a new logic that it will compare the scheduling with the presence inside the building and the windows openings. (Further to be done)
    c. Due to the consume of the ventilators, those can NOT be continuously running independently of the use, so a minimum threshold of demanding offices must be overpassed to switch on the ventilators. (Further to be done)

The three previous points control the sending water inside all building systems, its temperature and the air that will be delivered to the common ducts, that it will be used in each particular zone.

The orange squares that define set points, scheduling and further regulations can be exchanged by others simpler or complicated depending of different objectives searched, although in this document some controls will be proposed.

Control of the general water loop:

As it can be seen in the **Figure 1: General water loop control**, the calculation of the sending temperature and the ON/OFF's of the pumps (clear design and NOT dark blue design) depends of:

- the system that it is going to be used,
- the season and
- the occupancy of the building (scheduling)*.

*Also it can be seen that the sending temperature will be modified depending on the number of controlled rooms that are over a determinate *percentage of the building zones*.

The **Sending temperature calculator** fix a primary temperature needed to heat the building that will be decreased (saving energy) with the returning signals collected from the offices.

Pumps are always switched on: Pumps are switched by the general manager for the complete season or testing period. The maximum consume of the pump is 200W working at the maximum water delivering, but in normal operation use its electrical consume is proportional to the pressure drop seen by the pump. (Significantly under 200W, that makes not so useful to switch on/off a regulated pump.)

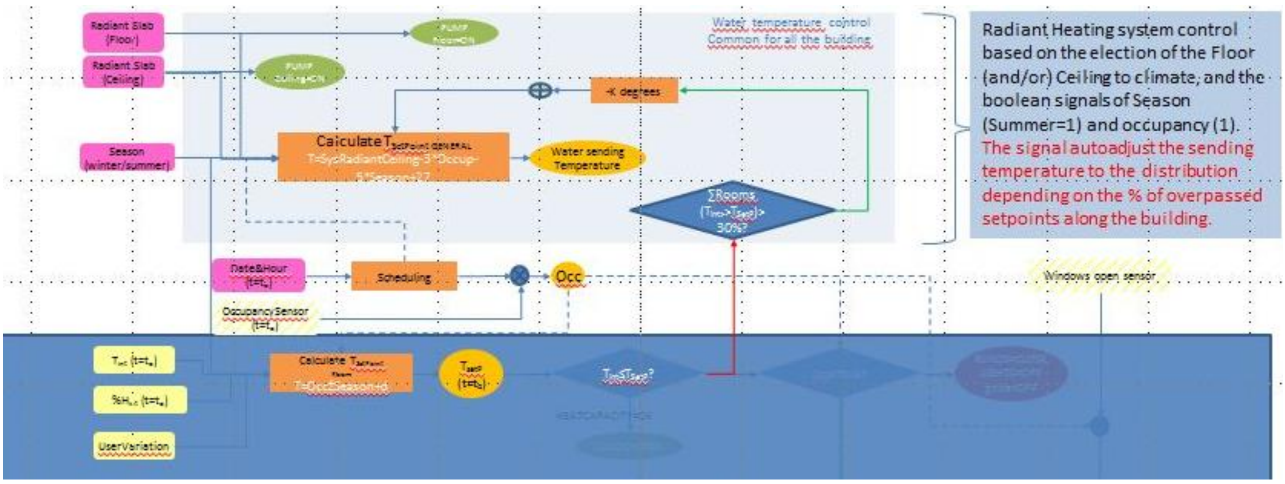


Figure 1: General water loop control

Until now, the building delivered a water flow temperature depending on the running average ambient temperature of the last 24 hours. The temperature is decreased in 4 degrees if the building was not occupied.

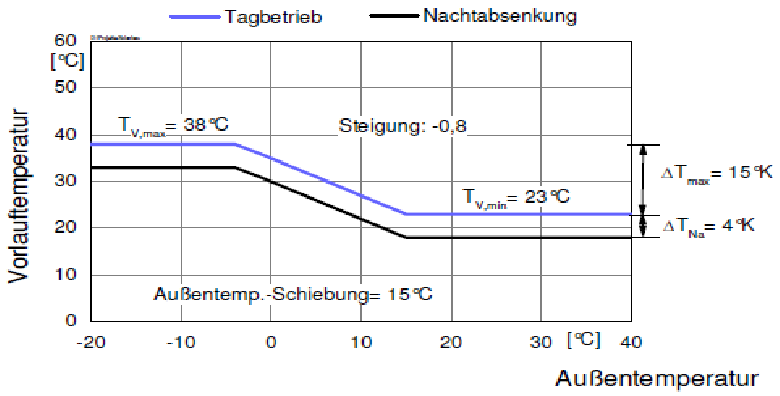


Figure 2: Actual norms to define water sending temperature

Control of the general air loop. Fan will be switched on only on demand.

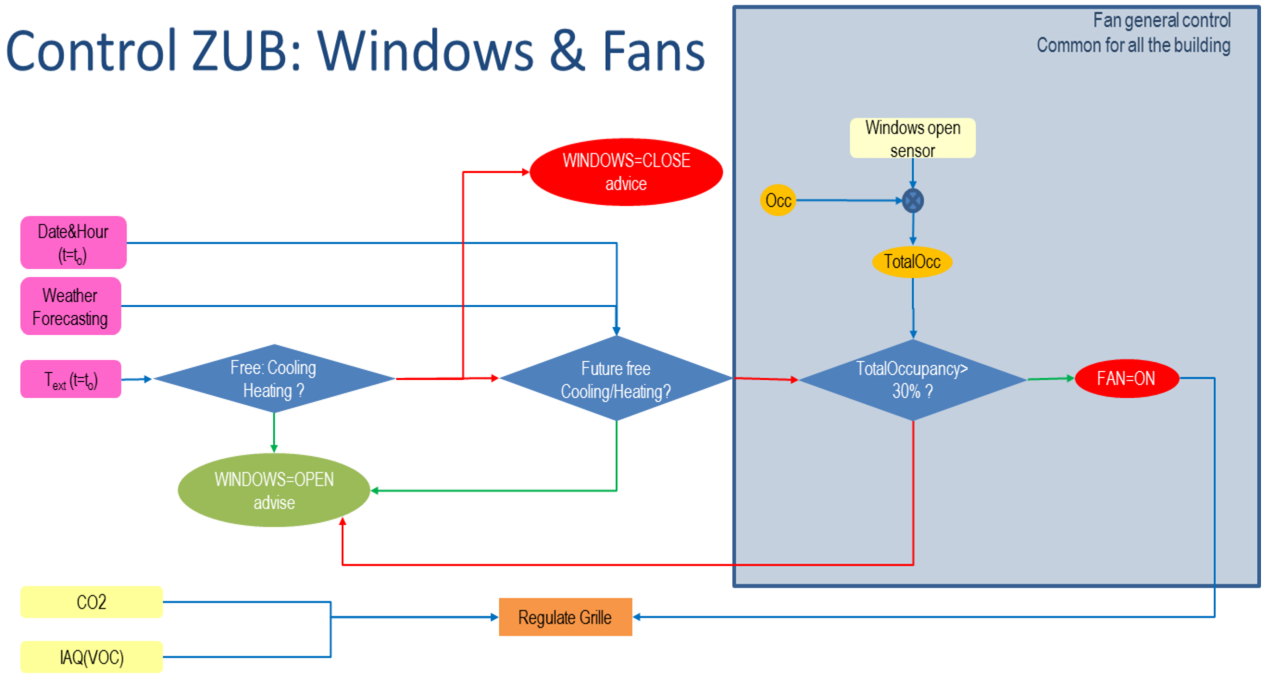


Figure 3: General Ventilation Control System

As it has been explained, the fans that deliver air to the building are not going to be permanently working in the case of a majority of offices in the building will have the windows open.

A new variable that define occupancy (TotalOccup) with the scheduling, occupancy sensors and each zone window open/close sensor, will create the possibility of **switching on the fan**.

Based on the external temperature, the system will compare the possibility of instantaneous free cooling strategies, sending advices to the office users with the importance of opening or closing the windows. Once that the minimum number of rooms have the conditions to be mechanically air cooled, the fan will be set to ON and each one of the newly existing regulating grids will open/close proportionally to the existing zone signals (mostly VOC's sensors, although CO_2 sensors also exist in the meeting rooms, and R1.06, 2.06), admitting only the air amounts that assure the perfect air quality. (Must be noticed that, until now the rooms always received air independently of the occupancy, and the air quality)

A common building forecasting must be still defined to advice the user in the last hours of the working day, if it is needed to open the windows for a night /weekend free cooling.

After these previous general controls, It will be defined the zone controls. All of them have a similar definition, permitting the creation of general control blocks that only must be multiplied for the number of controlling zones and connected to the correspondent zone sensors.

<u>Definition of the internal temperature set points (Zone by zone):</u>

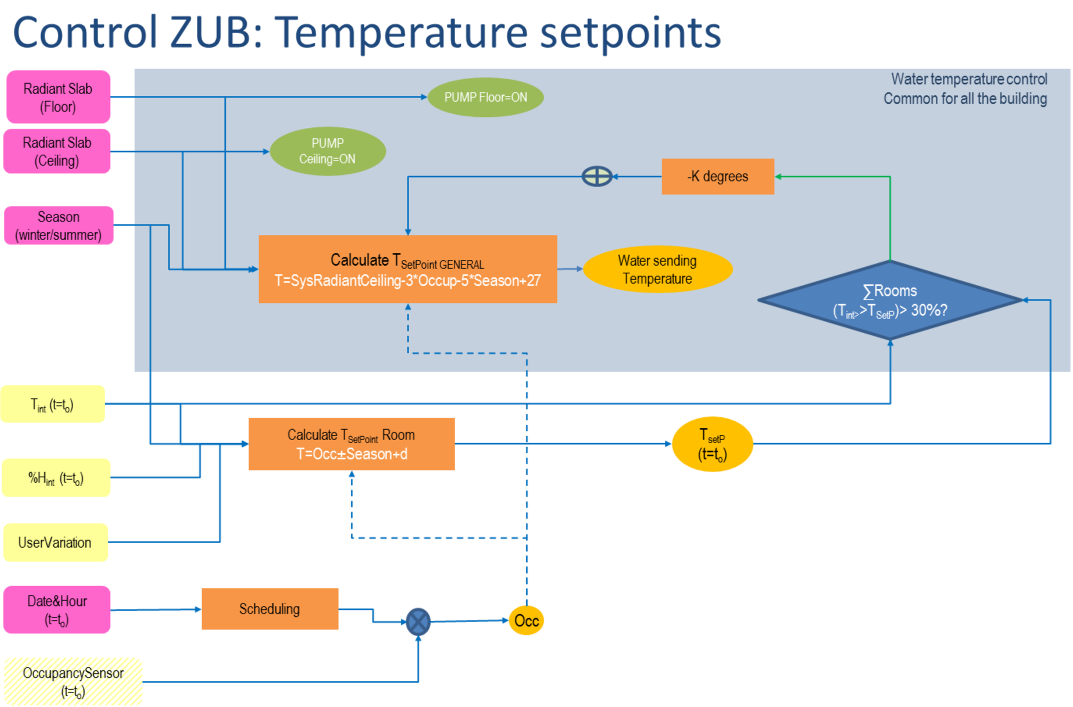


Figure 4: Definition of the Temperature set points

In the **Figure 4: Definition of the Temperature set points**, we show the control of the water temperatures sent to the building and the definition of the internal set point of each room based on the occupancy, dry temperature and preferences of the users (collected through the physical interfaces installed on one of the walls of each controlled room the wall).

Furthermore, some rooms (specially the testing rooms 106 206 and the lecture room) have the possibility of connecting instead of the dry temperature measured in the wall controller, 5 or 6 more different temperatures measured that could be connected to the “calculators”, permitting the study of controls based on different sensors and parameters (radiant temperatures, operative temperatures, sensors installed at different heights. …)

Definition of the light and blind controls (Zone by zone):

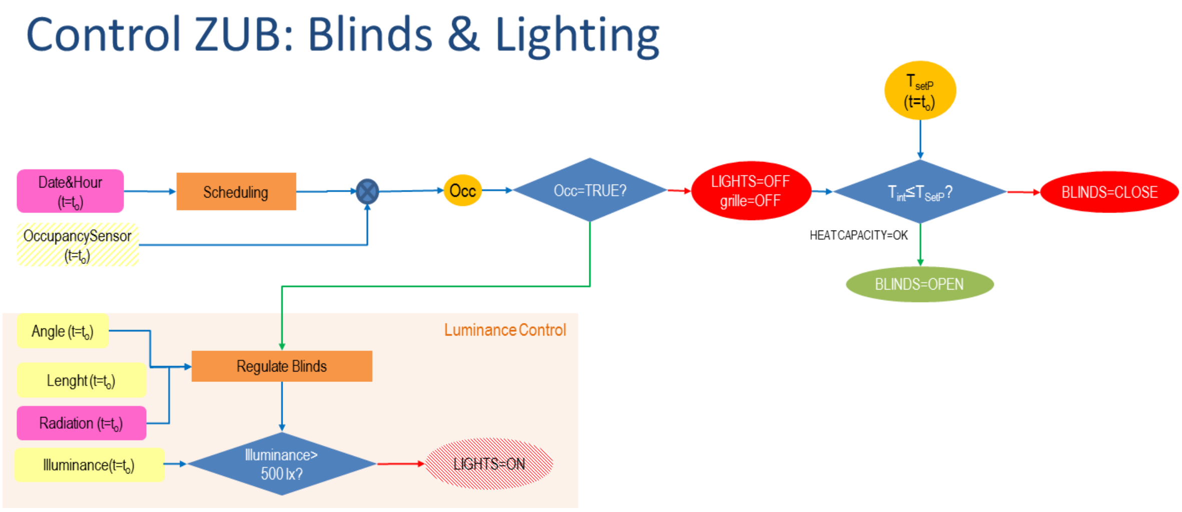


Figure 5: Light and blinds control

In this case, when there **is no occupancy** in a room, it will be defined directly the switch off for the lighting system and the air grilles. However, the blinds will be kept open or close, depending of the internal temperature and the set points searched.

If the actual temperature is over the set points plus a determinate hysteresis value, the blinds will be close to prevent the overheating in the building, while the other cases will keep the blinds over although there is no occupancy.

If there is **occupancy, luminance control** becomes priority. Then, the instantaneous horizontal radiation, day and time, last position of the blinds and the internal luminance sensor will permit a regulation of the blinds in case it would be needed. When the internal luminance sensor will not measure the minimum 500 lux needed for a typical office work, the lights will be switched on.

8 ANNEX 2: MATLAB Code example of Open_Window algorithm

The following annex will describe the process of opening window algorithm, written in MATLAB and perform the Converting linguistic rules to optimization Constraints, described at chapter 5.1:

```
% Implement rules for windows open/close
x1 = 25; % room temperature
x2 = 21; % outside temperature
x3 = 700; % room air quality
x4 = 9; % wind speed
x5 = 30; % room humidity (percentage)
x6 = 45; % outside air moisture
LM = 30; % center of Low moisture gausian - the value 30 is the minimum
        % anticipated measurement (We mean actually a one-sided gausian)
HM = 50; % center of High moisture gausian- - the value 50 is the maximum
        % anticipated measurement
cl = 5; % inclination of sigmoids

p1 = sprintf('RT = %3d  OutT = %3d  RAQ = %3d  WindS = %3d  RHM = %3d OAM = %3d',
x1,x2, x3, x4, x5, x6);
disp(p1);

% RULE 1
f_1(1) = logsig(cl*(x1-24));
f_1(2) = logsig(-cl*(x2-23));
f_1(3) = logsig(cl*(x3-600));
f_1(4) = logsig(-cl*(x4-10));

DOF_1 = 1;
for i = 1:4
DOF_1 = DOF_1 * f_1(i);
end
% DOF_1

sr1 = sprintf('f_1(1) = %5.3f  f_1(2) = %5.3f  f_1(3) = %5.3f  f_1(4) = %5.3f  DOF_1 = %5.3f',
f_1(1),f_1(2), f_1(3), f_1(4), DOF_1);
disp(sr1);
%pause;

% RULE 2
f_2(1) = logsig(-cl*(x1-21));
f_2(2) = logsig(cl*(x2-22));
f_2(3) = logsig(cl*(x3-600));
f_2(4) = logsig(-cl*(x4-10));

DOF_2 = 1;
for i = 1:4
DOF_2 = DOF_2 * f_2(i);
end
```

```
%DOF_2
sr2 = sprintf('f_2(1) = %5.3f  f_2(2) = %5.3f  f_2(3) = %5.3f  f_2(4) = %5.3f  DOF_2 = %5.3f',
f_2(1),f_2(2), f_2(3), f_2(4), DOF_2);
disp(sr2);
% pause;

% RULE 3
f_3(1) = logsig(cl*(x5-60));
f_3(2) = exp(-0.01*(x6-LM)^2);

DOF_3 = 1;
for i = 1:2
DOF_3 = DOF_3 * f_3(i);
end
%DOF_3
%pause;
sr3 = sprintf('f_3(1) = %5.3f  f_3(2) = %5.3f   DOF_3 = %5.3f', f_3(1),f_3(2), DOF_3);
disp(sr3);
% RULE 4
f_4(1) = logsig(-cl*(x5-40));
f_4(2) = exp(-0.01*(x6-HM)^2);

DOF_4 = 1;
for i = 1:2
DOF_4 = DOF_4 * f_4(i);
end
%DOF_4
%pause;
sr4 = sprintf('f_4(1) = %5.3f  f_4(2) = %5.3f   DOF_4 = %5.3f', f_4(1),f_4(2),  DOF_4);
disp(sr4);

a= DOF_1; b= DOF_2; c= DOF_3;  d= DOF_4;
DOF_ow = a+b+c+d + a*b*c - a*b -a*c - b*c - a*d - b*d - c*d - a*b*c*d + a*b*d + a*c*d +
b*c*d;
%pause;
sr5 = sprintf('approximate max(DOF_1 to DOF_4)= DOF_ow = %5.3f',  DOF_ow);
disp(sr5);
% RULE 5
DOF_cw = logsig(cl*(x4-10));
% pause;

sr6 = sprintf(' DOF_cw = %5.3f',  DOF_cw);
disp(sr6);
% Final output

action = logsig(10*cl*(DOF_ow-DOF_cw));

sr7 = sprintf('Final action = %5.3f',  action);
disp(sr7);
```