"INCOM" – Intelligent Network Control & On-site Monitoring
State of Progress report

INCOM Leak Detection System
Demonstration Program:
Task 6.1 **-** Elaboration of demonstration program
Task 6.2 - Deployment and initial testing of solutions
Task 6.3 - Execution of demonstration program
Task 6.4 - Adaptation of technologies solutions
Task 6.5 - Evaluation of Solutions

D5 Deliverables:
D6.1: Demonstration Program
D6.2: Demonstration of selected solutions
D6.3: Assessment Report

Task 6.1 - Elaboration and demonstration program:

CALM Water in collaboration with W-SMART and its sub-contractor CEA-LIST participated in a companion study sponsored by Eau De Paris and Suez / Societe du Nord at the University of Lille on Intelligent Network Control & Online Monitoring (INCOM) for early Network Leak detection and warning, which provided the framework for elaboration of the SW4EU demonstration program at the SUNRISE Demo-Site at the university of Lille.

INCOM project objectives were:

- Assessment of the current state of practice;
- Identification and adaptation of selected AI algorithms for process automation and simulation of the leak detection process currently used by Eau De Paris;
- Scenario simulations in order to assess the INCOM prototype system application for early network leak detection;
- Demonstration, integration into the INCOM enterprise system with customized HMI and evaluation through on-line system simulations.

The major goal was the development and feasibility assessment of an INCOM prototype system for early leak detection and sensors health monitoring using selected AI algorithms to simulate the operator's practice.

The first phase of the project consisted of:

1. Understanding the current operator's process, user's requirements and data analysis for leak detection
2. Creating databases using modified DMA flow meter data of Eau De Paris and AMR data at the SUNRISE demo-site of the University of Lille
3. Selecting the AI algorithms for the INCOM prototype system and their testing through off-line simulation of the Eau de Paris process, based on Minimum Night Flow monitoring, with the synthetic (modified raw) data.
4. Identifying the AI Algorithms for sensors health monitoring to detect sensing anomalies, which were identified by Eau de Paris as "mirror effect".
5. Working with W-Smart industry experts to establish users' requirements for risk based leak detection and sensors anomaly monitoring

Figure 1 illustrates the leak detection process (Eau de Paris data – Montiel et al. 2013) using daily comparisons of AMR based consumption and flow metering based distributed volume. Figure 2 shows an example of artificial mirror effects introduced over real water distribution time series of two adjacent (Auteuil and Passy) DMAs (CALM Water & CEA LIST Final Report, 2014).

Based on the data analysis and off-line leak detection simulations conducted as part of the INCOM companion study during the first year of the project (2014) and industry experts' recommendations the current demonstration program was established and implemented with the University of Lille aas its demonstrator site.

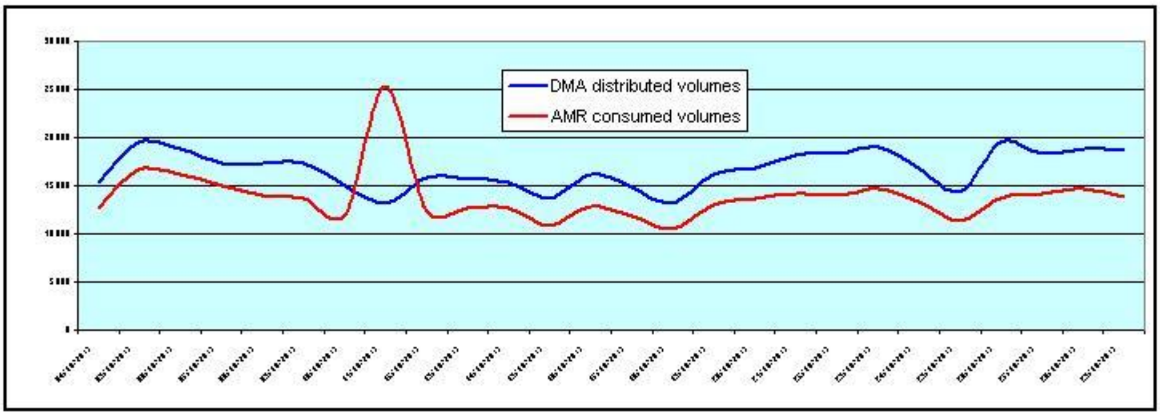

Figure 1 – Comparison of distributed and consumed volumes over a DMA (Eau de Paris data – Montiel et al., 2013)

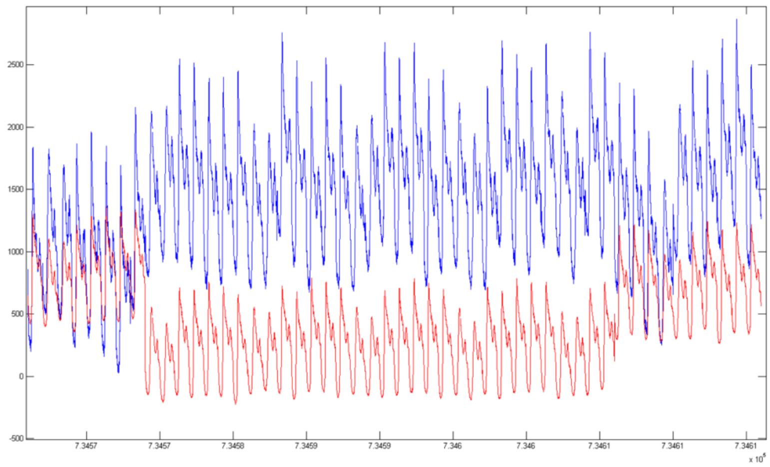

Figure 2 – Toy example of artificial mirror effects introduced over real water distribution time series of the Auteuil and Passy DMAs (CALM Water & CEA LIST Final Report, 2014)

Task 6.2 - Deployment and initial testing of solutions.

Objective: Following the program developed under Task 6.1, the demonstration of the INCOM prototype system currently involves the following steps:

1. Establishing with W-Smart users' requirements for demonstration of INCOM prototype system application for leak detection
2. Integration of the identified AI modules into the INCOM enterprise platform for scenario simulations of leak detection using several modules:
    a. Minimum Night Flow (MNF) data
    b. Historical data based reference curve of distributed volume through comparisons with actual DMA flow meter data

c. Comparisons of AMR daily consumption data and distributed volume data for each DMA

3. Demonstration of INCOM prototype system application for sensors health monitoring through off-line simulations of mirror effects
4. Pilot demonstration of the INCOM prototype system through off-line leak scenario simulations of the SUNRISE Demo-site network at the University of Lille, using AMR data and Distributed Volume data at the inlets.

The INCOM prototype system development required:

- Pre-processing and processing steps which respectively consist in cleaning data and exploiting them for actual mono-parameter events detection;
- Filtering out false alarms due to non-specific water quality indicators and their high temporal variability.
- Evaluation of the methods for the illustration of the post-processing step, which supports the final alarm triggering by crosschecking different sources of information;
- Selection of the approach for the integration of the INCOM prototype for feasibility assessment.

Synthetic data obtained from modified Eau de Paris DMA Flow meter data were used to test AI algorithm application for leak detection and filtering false alarms.

As shown in Figure 3, by clicking on one of the scenario controller boxes, the algorithm will work on offline data and detect anomalies, which will then be displayed in the alarm panel. The alarm panel acts as the real-time detector and historical recorder of anomalies by operators or engineers. It provides a level of confidence in its determination based on requirements of operators at EDP.

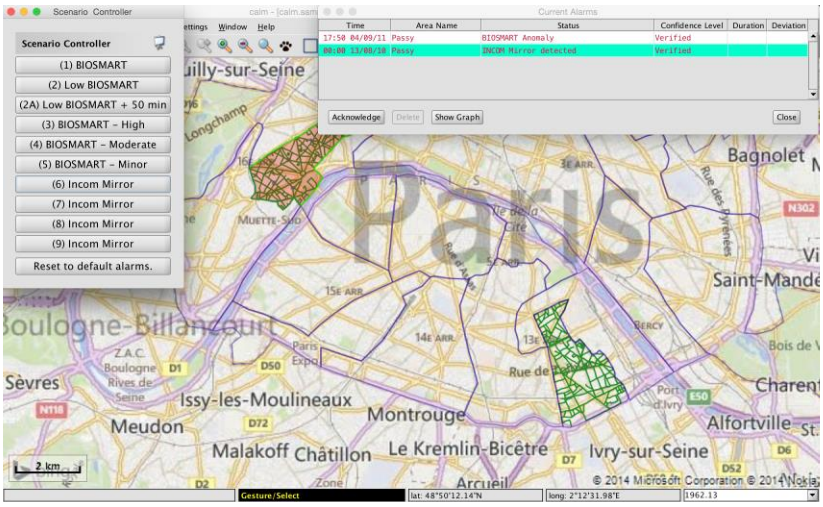

Figure 3 - Alarm Panel showing existing alarms with Passy DMA blinking prior to being acknowledged by the operator of the decision support system.

As shown in figure 4, the operator could click on the alarm panel graph button for a specific alarm and visualize the detected anomaly data. The graph can be manipulated to allow the operator to drill down on a detected anomaly.

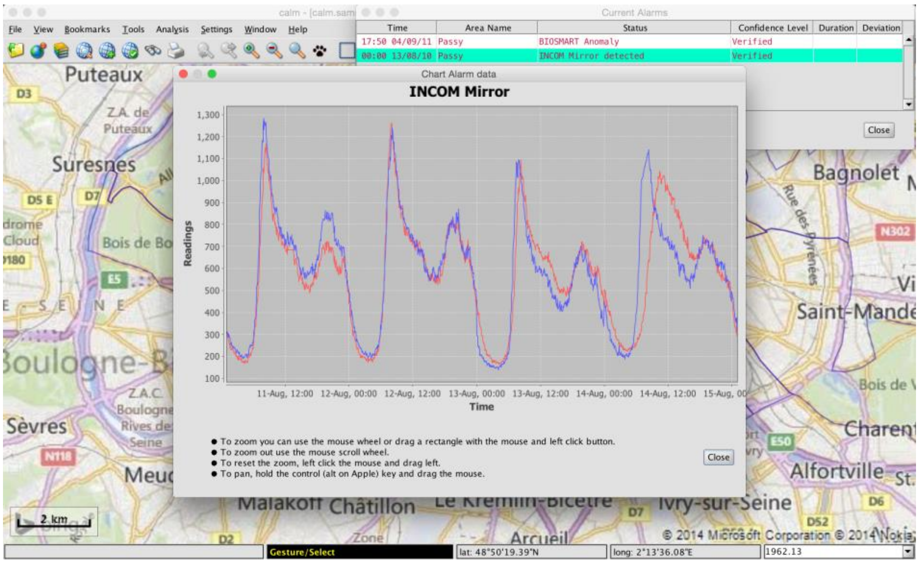

Figure 4 - Graphical Manipulation with C2SOS

The current INCOM prototype system has been customized for a mono-parametric automation of the leak detection process currently used by the operator. The statistical analysis module integrated in the prototype system enables the operator to assess:

- The "confidence level" of the likelihood of an hydraulic anomaly such as leak by displaying a time series of a Likelihood Indicator I_L
- The severity of the anomaly (constant or progressive) by displaying a time series of a Severity Indicator I_S
- The risk of the anomaly by displaying a time series of a Risk Indicator I_r (integrating likelihood and severity)

Figure 5 illustrates the configuration and characterization of the Lille demonstration site, divided into two DMAs, which are controlled by virtual flow meters (for which flow velocity has been estimated using the EPANET model). Figure 6 shows for these DMAs and for the entire site the comparisons of Distributed Volume (calculated with EPANET) and Consumed Volume (measured with AMRs), illustrating the consistency of the virtual DMAs configuration.

Figure 5 - illustrates the configuration and characterization of the Lille demonstration site

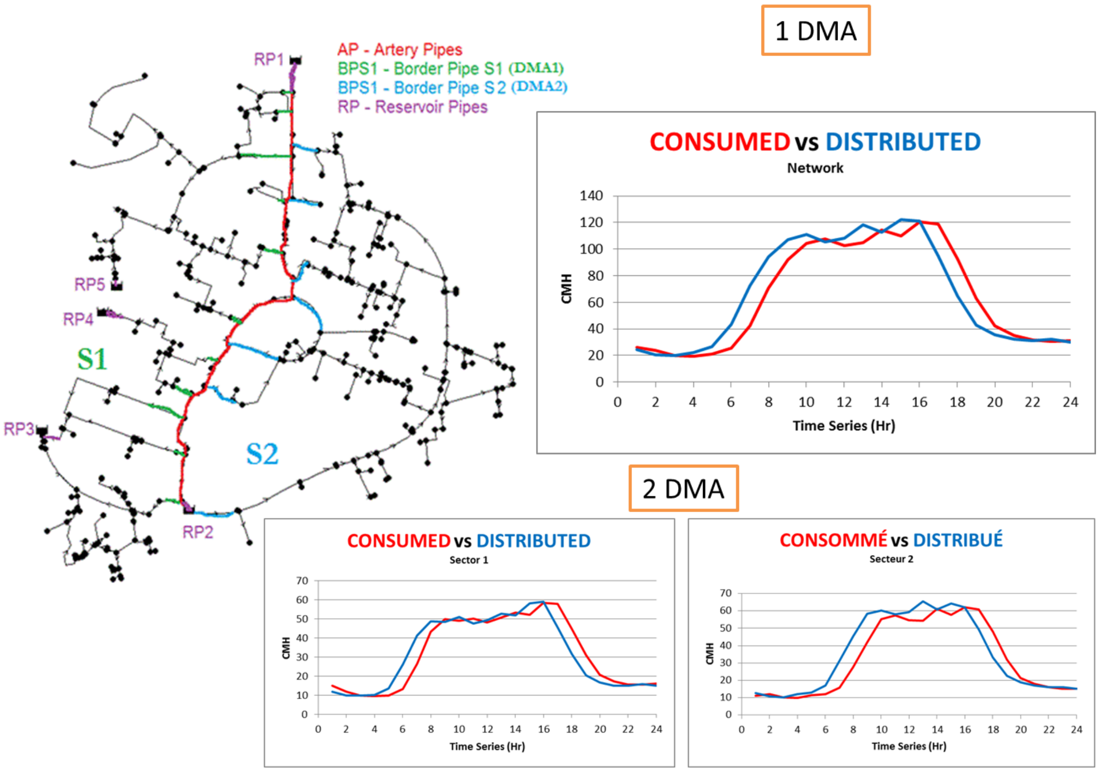

Figure 6 – DMA'S Comparison of Distributed & Consumed Volumes

Figures 7, 8 and 9 illustrate the INCOM process and the statistical analysis output for estimating the Likelihood, Severity and Risk Indicators of Leaks while using the Confidence Interval for early anomaly detection and eliminating false alarms.

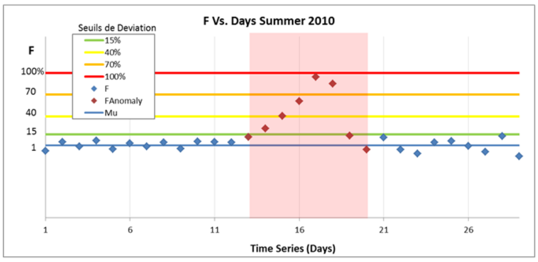

Fig. 7a. Time series of standardized MNF (F) values and deviation thresholds (ΔF%)

Likelihood Matrix					
	Days				
ΔF% on avg.	1	2	3	4	>4
0-15%					
15-40%					
40-70%					
70-100%					
>100%					

Fig. 7c. Leak Likelihood

Severity Matrix					
	ΔF%				
ΔS%	0-15%	15-40%	40-70%	70-100%	>100%
0-15%					
15-30%					
30-45%					
45-60%					
>60%					

Fig. 7d. Leak Severity

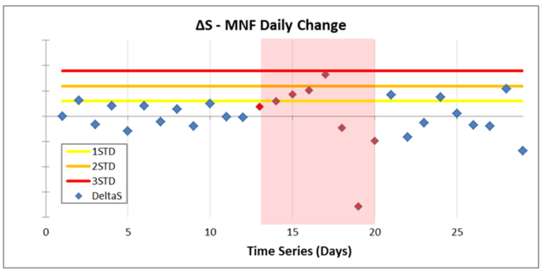

Fig. 7b. Temporal leakage variation (defined by the increment of the 24-hour deviation)

Risk Assessment Matrix					
Severity Scale					
Likelihood	1	2	3	4	5
0-10%					
10-30%					
30-60%					
60-90%					
>90%					

Fig. 10e. Risk of leak

Figures 7 - INCOM process demonstration for a progressive leak

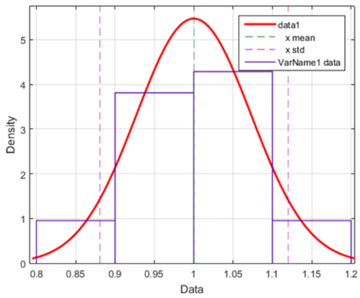

Fig. 8a. Distribution of MNF Standardized (F)

Z SCORES FOR ALPHA (α)			
Confidence Interval	Alpha	α/2	Z Score
68%	0.32	0.16	± 1.00
90%	0.10	0.05	± 1.65
95%	0.05	0.025	± 1.96
99%	0.01	0.005	± 2.58
99.90%	0.001	0.0005	± 3.29

Fig. 8b. Alpha α – Confidence Interval (IC)

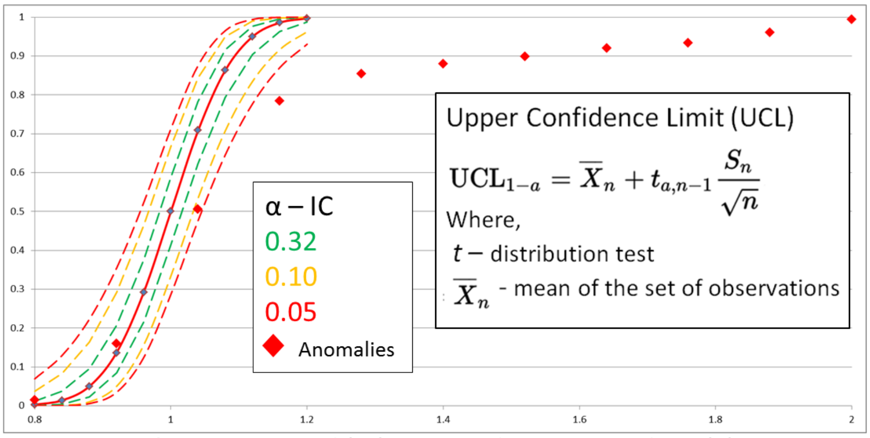

Fig. 8c. Confidence Interval (IC) – Normalized MNF values (F)

Figure 8 – INCOM Statistical Process

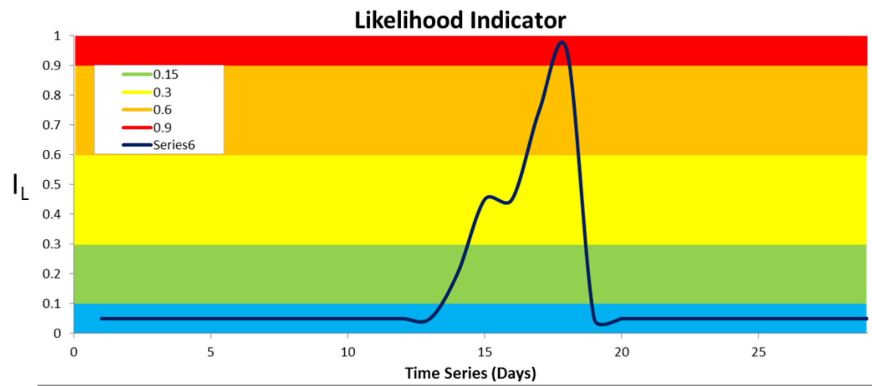

Fig. 9a Likelihood Indicator

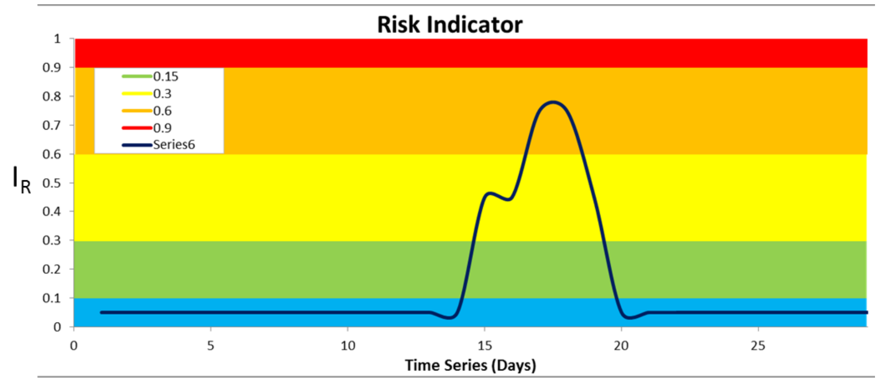

Fig. 9b Risk Indicator

Figures 9 - INCOM Likelihood and Risk Indicators of Leaks

Figures 10 and 11 illustrate the application of the INCOM process for the detection of an instrumentation anomaly characterized as the Mirror Effect. User's Interface is presently being adapted to enable the operator to select "confidence levels" (coded in color) for decision support in early warning systems. Alternatively, values by default can be used which are continuously determined and updated by statistical tools (standard deviation, confidence interval, etc.) throughout a real time-data feeding process.

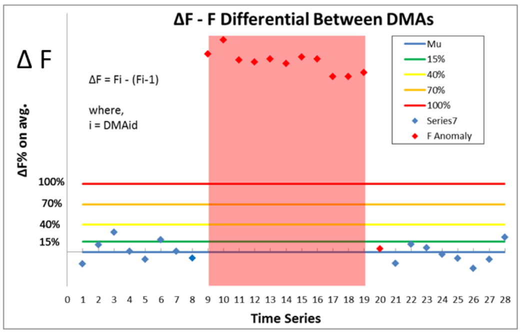

Fig. 10a. $\Delta F = F_i - F_{(i-1)}$
F_i = VD (DMA_2) & $F_{(i-1)}$ = VD (DMA_1)

Likelihood Matrix					
	Days				
ΔF% on avg.	1	2	3	4	>4
0-15%					
15-40%					
40-70%					
70-100%					
>100%					

Fig. 10c. Likehood of Mirror Effect

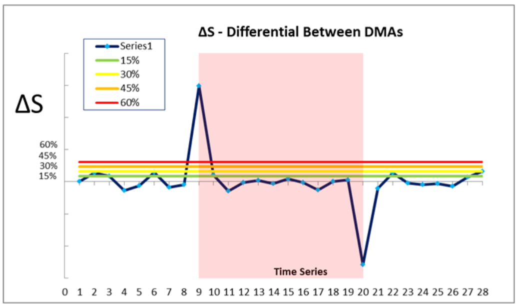

Fig. 10b. ΔS = Variation de ΔF per 24hrs

Severity Matrix					
	ΔF%				
ΔS%	0-15%	15-40%	40-70%	70-100%	>100%
0-15%					
15-30%					
30-45%					
45-60%					
>60%					

Fig. 10d. Severity of Mirror Effect

Risk Assessment Matrix					
	Severity Scale				
Likelihood	1	2	3	4	5
0-10%					
10-30%					
30-60%					
60-90%					
>90%					

Fig. 10e. Risk of Mirror Effect

Figures 10 Application of the INCOM process for the detection of an instrumentation anomaly characterized as the Mirror Effect

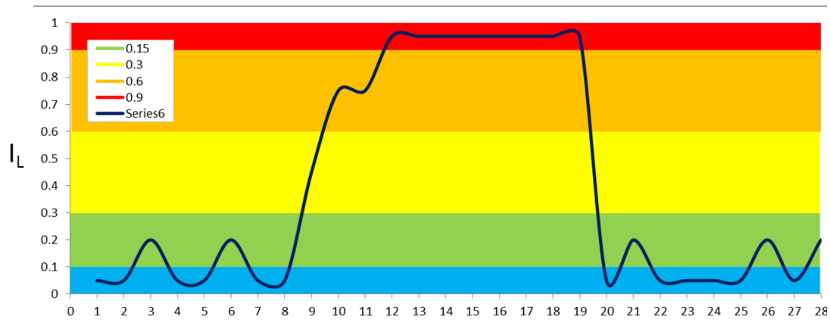

Fig. 11a Likelihood Indicator of Mirror Effect

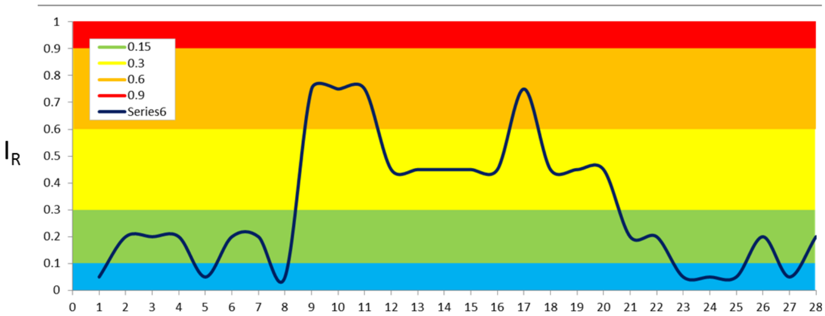

Fig. 11b. Risk Indicator of Mirror Effect

Figures 11 Likelihood and Risk Indicators for Mirror Effect

The next phase of tasks 6.3 and 6.4 will consist of:

1. Integration of the selected AI algorithm into the enterprise platform of the INCOM prototype system.
2. Creating a database with a data processing algorithm for presentation of the output anomaly for demonstration of the algorithm application.
3. Using utilities GUI system to show the proper filtering, data processing and application of these algorithms on this data in simulation, which is the main deliverable for this task.
4. Demonstration of the INCOM prototype system through leak scenario simulations in the SUNRISE Demo-site at the University of Lille, using AMR Data and engineering model simulations driven data.