Large Scale Integration of Wireless Sensor Network Technologies for Air Quality Monitoring at a Logistics Shipping Base

Judith Molka-Danielsen
Dept. of Logistics
Molde University College
6402 Molde, Norway
j.molka-danielsen@himolde.no

Per Engelseth
Dept. of Logistics
Molde University College
6402 Molde, Norway
Per.Engelseth@himolde.no

Hao Wang
Dept. of ICT and Natural Sciences
Norwegian Univ. of Sci. & Tech.
Ålesund, Norway
hawa@ntnu.no

Abstract— **The future of logistics shipping bases will be to seek efficient flows of materials to meet the needs of business partners. Supply chain and operations managers of supply bases will need to integrate technologies that allow for greater automation, digitalization, flexibility and improved communications among stakeholders. The technologies that are likely to boost integration will consist of a plethora of Industrial Internet-of-Things (IIoT) technologies that may include Wireless Sensor Network (WSN) technologies and could be applied for improved monitoring of healthy and safe industrial workplaces for workers. However, little is known regarding how WSN technologies can be implemented on a larger scale and its implications when integrated on standard logistics and operations of industrial workplaces such as a shipping base. The WSN sensor units represent an integrating resource that are capable of monitoring air temperature, humidity and levels of carbon dioxide (CO2) and other gasses and of disseminating this information to different actors in the production system. Air quality factors play a critical role in the perceived levels of workers' comfort and in reported medical health. The low cost of wireless sensor network (WSN) technologies offer potential for continuous, autonomous and importantly networked assessment of industrial workplace air quality that may have implications for operations management and quality of production. This paper initially presents a case study that monitors air quality that is collected with WSN technologies from two workshops carried out by a large on-shore logistics base that supports offshore petroleum logistics. The case study demonstrates a monitoring and visualization approach for facilitating BD in decision making for health and safety in the shipping industry. However, with the advancement in IIoT technologies and the emergence of smart sensing and actuating devices, it is possible to form a *digital closed-loop* system that we argue is essential for managers to link together information about air quality with supply chain and operations management decisions. We propose that central to effective decision making is the data analytics approach and visualization of what is potentially, big data (BD) in monitoring the air quality in industrial workplaces. We discuss how WSN technologies can be integrated into the logistics management and operations of the shipping base. Through an analytical discussion of BD we explore how to extend the potential application of IIoT and Visual Analytics to facilitate a smart workplace for the Industry 4.0 era.**

Keywords—Big Data analytics; IIoT; Wireless Sensor Network Technologies; health and safety; shipping industry; air quality.

I. Introduction

Logistics shipping bases offer complex varieties of handling and transportation services supporting offshore petroleum search and production activities. This complex working environment requires that all parties operate and manage business with a clear understanding of Health, Safety and Environment (HSE) requirements. For these businesses much is invested in the systems of preparedness and response. In this context, Industrial Internet of Things (IIoT) technologies in particular WSN sensors and networks can be applied to improve the monitoring of healthy and safe industrial workplaces; in such cases increasing connectivity between people at work and their managers to secure workplace quality. In particular, indoor air quality is important for worker satisfaction, safety and health. Measures of air quality that are used in general assessment of air quality include: CO2 levels, temperature, and relative humidity. Specialized organizations can be brought in to measure air quality in designated test sites for limited periods. However, there can be variability in measurements due to periodic organization activities.

Safe workplaces in the petroleum industry, such as on-shore shipping bases, encompass a duality of ethical concern that seeks to ensure as well the quality of oil production. The logistical shipping base can be described as a node in the supply chain that supports everyday production on the offshore platform. The shipping base is part of a complex network that is prone to a high degree of uncertainty [1]. Ensuring quality working conditions is from an ethical viewpoint an aim in itself. However, the spill-over of securing worker well-being also secures quality production in the complex system that on-shore and off-shore petroleum production inherently is. This means that securing an environmentally safe workplace at the logistics supply base must be seen as a part of its networked system characterized by interacting complex supply and production processes.

"Industry 4.0." denotes increasing automation and data exchange in manufacturing technologies; cyber-physical systems, the IIoT, cloud computing and cognitive computing. Strange and Zucchella [2] report that the digital technology can disrupt how and where activities are located and organized supply chains, and which of the network actors registers and informs about the value-adding transformations. They also report that Industry 4.0 is still in its infancy, but that its effects are already having an impact upon the nature of competition and corporate strategies in many industries. Using 4.0 technologies implies what in our case concerning production at a supply base may be called "smart logistics". In supply chains, it is especially the velocity feature of big data (BD) that is pertinent in developing production. How can production as a complex process be quickly informed about and founded in improved information connectivity? This means that handling large volume of ever-changing data demands IT-enabled connectivity between the many and divergent supply chain actors.

Through enhancing data capture regarding the workplace environment not only secures the reputation of the logistics supply base operator, in its network through securing transparency regarding the quality of its operations, it also means that process improvement may at an earlier time be detected and thereby ensuring improvements of working conditions. Automating the workplace environment through monitoring systems can be regarded as an in part automated improvements and continuous process improvement dependent on the state of integration in the supply chain. Such systems may therefore be integrated with a company's overall production quality system. Industry 4.0 technologies may be used to enable improved production quality systems through, for example, predicting malfunctions and responding in real time, such that planning for production can be improved. In a specific example, General Motors is using WSN sensors to measure humidity levels in its plants. Should humidity levels get too high, machinery or materials are automatically re-routed to less affected areas. This creates better production conditions by reducing the need to repaint some shop floor materials, thus avoiding downtimes in the production process [3].

Studies also support that production quality is not independent of worker safety. European regulations that are applicable for example to our case company already require employers to take preventive measures for HSE to make work safe [4]. Industry 4.0 technologies through tracking and monitoring of workers within operations environments can help facilitate the transformation of workplaces to be safer and more efficient. The company Boeing, for example, has used sensors to detect the status of safety harnesses [5]. Sensors can be used to monitor workers' movements, productivity, and in real-time safety monitoring. Sensors can measure atmospheric criteria, e.g. gases, temperature, humidity, or they may measure factors that are internal to workers' biometrics, e.g. temperature, blood pressure. Monitoring through WSN sensors could allow workers to perform work in potentially dangerous environments, including small confined spaces, to work in spaces where dangerous concentrations of gasses can accumulate. Having the ability to pinpoint the workers or locations and the status of a safety environment can improve worker safety, and result in increased productivity and worker effectiveness. The concept of "connected safety" is at the forefront of the smart workplace. Future Industry 4.0 developments in smart workplaces will aim to enhance worker protection while seeking the dual goal of improving productivity.

Because of the advancement in IIoT technologies, the emergence of smart sensing and actuating devices makes it possible to form a *digital closed-loop* system as depicted in Figure 1. It is our vision to build up a smart closed-loop system to ensure logistics workplace safety.

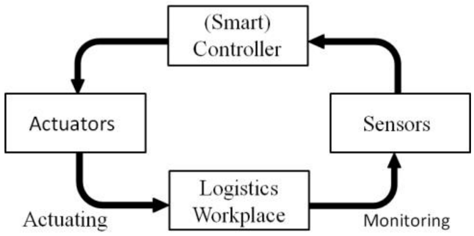

Fig. 1. A Smart Closed-loop System for Workplace Safety

In this paper, we focus on the monitoring part. We first present a pilot monitoring of air quality in two building workspaces at a logistics shipping base Vestbase AS in Norway. This company uses Lean techniques to secure continuous quality improvement of the services it offers its customers. The described workplace environment monitoring system may accordingly represent a component in an overall Lean process development scheme. We identify the two trial areas as Building 11 (B.11) and Building 43F (B.43F). Building 11 is an enclosed workshop where vehicles and equipment for base operations (e.g. forklifts) are repaired. Building 43F is a semi-enclosed area where there are high water pressure activities for cleaning pipes. We selected these two areas as the trial areas, because we think that they can also represent off shore workplace environments, such as oil platforms. Therefore, the findings of this study have relevance for other workplace settings.

We propose a system analytics approach of how to manage the "big" data in determining air quality at an industrial workplace. Recent low cost wireless sensor network (WSN) technologies give opportunities for organizations to set up for longer-term or continuous air quality measurement of workplace spaces. The small size and self-sufficient characteristics of the sensor devices allow for their flexible placement. They can be used, for example, to measure the air quality in a redesigned building, in an area of reported problems, or during a period of increased industrial activities.

Although we are measuring levels of CO2 in this case study, the WSN and BD analytics can be used for worker safety in high risk areas (e.g. to monitor presence of high risk gases such as hydrogen sulphide – H2S, carbon monoxide – CO, etc.) and for quality of goods in supply chain management. In such environments it would be ideal to also view the graphical presentation of the data in real-time, such that in other workplace environments (e.g. high risk industries) BD could be monitored for spikes in air quality measurements.

Finally, this paper presents a theoretical discussion of how WSN technologies can be integrated into the logistics management and operations of a logistics shipping base. In our discussion we elaborate on the visualization approach for facilitating BD in decision making for health and safety in the shipping industry. In doing so, we explore how to extend the potential application of WSN technologies and visualization of information in the broader workplace environment.

II. LITERATURE REVIEW

A. Industry 4.0 and Operations Management of the Supply Base

Within the petroleum industry, safeguarding people at their workplace is a key concern [6]. This is natural given the immense risk of production failure at offshore installations. For example, each morning at a control centre in a small western Norwegian town managing production at an offshore platform, human resources is always the first topic covered in the daily plenary meetings [1]. This ethical concern regarding worker well-being is, however, likewise found as an industrial culture at the land facilities, such as the logistics supply base.

The quality of production at the supply base is reviewed by multiple stakeholders on a daily basis and on a long-term basis. On the everyday level the aim is to uphold operations. On the long-term basis, the aim is for the supply base to secure contracts for its future services by document quality production which includes adhering to given safety standards including excelling these and being able to document this quality of production. In this production setting of networked and sometimes vexed stakeholder interests regarding labour safety, it is imminent that these stakeholders be informed about the quality of production at the supply base by upholding system transparency. The monitoring of air quality at the workplace therefore is used first to inform management on the state of operations environment. If monitoring reveals that operations involve hazardous conditions for the workers, then steps need to be taken to improve the workplace environment. In operations management flexible manufacturing entails investing in and using resources that not only automate production, but also involve responsiveness to environmental change. According to D'Souza and Williams [7] manufacturing flexibility encompasses variation in external and internally driven factors, such as volume, product variety factors, manufacturing process flexibility and materials handling flexibility.

Wycisk et al. [8] state that it is valid to call supply networks complex systems. This implies that supply networks are vulnerable to nonlinear dynamics in business practice. These authors found that the use of a neural network model could work to manage these new challenges. In brief, the studied air quality monitoring system represents a module in flexible production adapted to a logistics organization. Focus in this development is not on manufacturing, but on how logistics processes, transport storage and materials handling are coordinated.

B. Measurements of Air Quality

Various indoor air quality studies in Norway have examined the air quality in modern energy efficient buildings. The parameters measured have included air temperature, relative humidity, and CO2 concentration. Some have also measured particulate matter concentration [9] [10]. Earlier studies have shown that office workers frequently report health issues of fatigue, heavy-headedness, and eye irritations [11]. [9] states that in some buildings the ventilation systems are controlled manually (constant flow), and in other newer energy efficient buildings ventilation systems can be controlled by temperature and CO2 demand-controlled sensors (variable flow) systems. In such buildings sensors are used to measure temperature and CO2, and the ventilation flow is increased when CO2 levels rise above 899 ppm, or 22.0 ^{0}C. The Norwegian Work and Environment Act [12] recommends that the standard value upper limit for CO2 concentration in an indoor environment of 1000 ppm (parts per million). Indoor temperatures should be maintained between 20.0 - 22.0 ^{0}C. Indoor temperatures above 22.0 ^{0}C are reported to be unpleasant and that working efficiency falls with higher temperatures. Relative humidity indoors will change depending on the relative humidity outdoors. Ideally it should be between 30% - 60% relative humidity indoors [13].

There is research that examines relationships between workplace air quality and worker satisfaction or performance. One study conducted in Norway by [14], finds that low relative humidity in recently built airtight and auto-mechanically ventilated buildings is associated with lower performance of office workers. Another study [15] examines energy efficiency and user comfort in comparing Norwegian cellular offices versus British open plan workplaces. In that study workers in the Norwegian offices had control over the thermal system, and reported higher comfort and satisfaction as compared to the ratings by the British workers who were working in airtight and auto-mechanically controlled environment. These studies highlight that building management of ventilation systems can be factors in worker performance and satisfaction.

In any environment, indoors or outdoors, workers should not be exposed to more than 5 000 ppm for an 8-hour workday, with a ceiling exposure limit of 30 000 ppm for a 10-minute period, the risk of higher concentration is explained in Table 1 [16]. For the workers, it is important to stay focused. The CO2 level is not the only thing that affects the perceived state of wellbeing. The other factors influencing the air quality are temperature and relative humidity.

TABLE I. CARBON DIOXIDE LEVEL INFLUENCE ON PEOPLE

Concentration of CO2 in the air	***Symptoms***
350 - 450 ppm	Typical atmosphere
600 - 800 ppm	Acceptable indoor air quality
1 000 ppm	Tolerable indoor air quality
5 000 ppm	Average exposure limit over 8 hours

Concentration of CO2 in the air	Symptoms
6 000 – 30 000 ppm	Concern, short exposure only
30 000 – 80 000 ppm	Increased respiration and headache
100 000 ppm +	Nausea, vomiting, unconsciousness
200 000 ppm +	Sudden unconsciousness, death

C. Wireless Sensor Network Technology

To monitor the work environment our case study proposes the use of autonomous wireless sensor network (WSN) sensors. There are two approaches to detect CO2 using sensors. The first one is measurement using method of wavelength absorption that is one of the properties of chemical compound. This method is called NDIR (not dispersive infrared) [17]. The second method is based on changes of electrical charge of chemical reaction measuring. This reaction is a result of air contact (CO2 particles) with particles in the sensor. The most used detection method is using NDIR sensors [18], but the price of sensors is quite high (between 100 and 1000 euro). We use the second method, MQ-135 sensor that provides monitoring of air quality and with calibrated settings it can be used as sensor for CO2 detection.

The MQ-135 sensor is designed for the use in air quality control equipment for both industrial buildings and offices. It is suitable for detection of NH3, NO3, alcohol, Benzene, smoke and CO2 [19]. To obtain real values of CO2, X-NUCLEO-IKS01A1, Motion MEMS and environmental sensor expansion board for STM32 Nucleo have been used.

The CO2 sensor unit used in this study is depicted in the right part of Figure 2. All sensors can function indoors or outdoors. The functions of the different units are listed as follows:

- gas detector: measuring CO2 and NO3 in given area
- temperature, relative humidity and pressure measurement

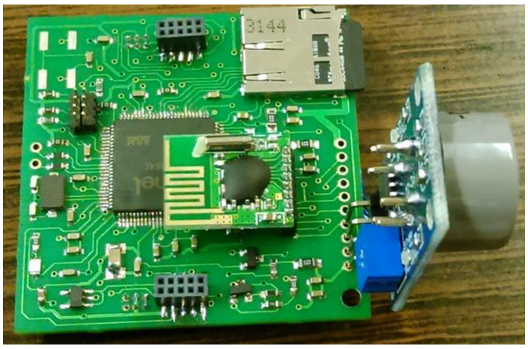

Fig. 2. WSN sensor units for CO2, with alternative communication module

D. Big Data & Visual Analytics

The concept of "big data" was introduced by the META Group [20] where they discussed how enterprises would use data to increase business opportunities. They characterized data by "volume" (how much), "velocity" (speed of data into and out of the organization) and "variety" (range of data sources or data types). These became known as the 3Vs of big data. Other "Vs" have been studied, such as "veracity" (quality of data source) and "variability" (inconsistency of data source). In [21], a list of 52 mainstream sources of Big Data (BD) across supply chains were compiled. This data varies by degree of structure, volume and velocity. The dimension of 'structured-ness' indicates three types of data: core transactional data, internal systems data, and other data. They indicated that greater enterprise resources are generally spent on the preparation, management and use of the core transactional data. However, there is little empirical evidence regarding the effect of management and use of the unstructured big data in Supply Chain Management (SCM). Unstructured BD can be sourced in large volume and rapidly acquired from GPS-enabled or social-media-enabled applications. Recent approaches in visualization and geo-analytics have allowed data generated outside of the main enterprise to contribute to knowledge-sharing activities, collaboration and integration of the supply chain network. Traditionally there has been a trade-off, that by increasing structuration, data becomes more applicable for internal use by a firm. Yet big data involves a layered continuum picture from largely controllable internal data, through intermediately controllable supply chain data, and to less controllable environmental data. While we only examine internal data generated within the workshop for this study, future research is needed to develop approaches for the intelligent analysis of BD that are potentially generated by other sources. One could imagine tracking the temperature of a product on a pallet, during transport off-shore, and in warehouse on-base. From end-to-end of the supply chain, there may be different sensors reporting. Efficient and effective analytics on monitoring data from workplace lay the critical foundation for decision-making in actuating part of the closed-loop.

Note that human must be kept in the loop and be notified with critical updates. This entails an important aspect for BD analytics: visualization. Hilbert in [22] points out that the promises of BD is not about only dealing with data in greater quality and quantity and from greater variety of sources, but to be able to use the presentation of the data for intelligent analysis and decision making. Additionally, [23] point out, the new role of data in SCM is to change data into actionable information within the role of business analytics. In general, for data to be useful at decision making points, such as in planning and forecasting, it must leverage the humans' visualization system and their ability to spot patterns, trends and outliers. *Visual Analytics* (VA) [24] combines automatic analysis techniques with interactive data visualisations. Fekete et al. [25] has rigorously explored the benefits of data visualisation. Even as the algorithmic analytic methods can quickly identify useful information and provide more accurate prediction, they lack the ability to interact with human and deliver effectively the knowledge. The combination of visualisation and algorithmic analytic methods enables a virtuous cycle of user interaction, parameter refinement for algorithmic models so as to achieve rapid correction and improvement of human's knowledge and decisions. In the Discussion section we further reflect on the benefits and challenges of BD and VA for workplace safety based on the outcome of our study.

III. METHOD

This research applies a descriptive analysis of the pilot monitoring of air quality using WSN sensors in two buildings. The research method and approach for data collection and analysis is described in this section.

We conducted trials in two workshop locations, such that the WSN sensors were placed for two and one week periods. The devices were placed indoors on a ledge. They were not placed close to the air conditioning vents and doors. They were placed at an ideal height of 1.5 – 2.5 meter above the floor. The devices are autonomous, self-sufficient. They are powered from 5V source or from the batteries if they are deployed in an outdoor environment.

WSN sensor networks are typically composed of a large number of sensor nodes that are placed in a target monitoring area and communicate with each other. Many studies have focused on how to extend the life of the networks including criteria such as when particular nodes in the network sleep, when is data transferred to the sink, and the sensing frequency. [26][27][28] The simplicity of our case study environment makes in unnecessary to apply optimization approaches in our monitoring. However, due to high rate of battery consumption of the WSN unit, the units were supplied by the adapter from the electrical network all the time.

In each trial we had only one sensor per room that was available. The installed sensor unit included components on the unit board to simultaneously collect measures of CO2, relative humidity and temperature. It would, however, be simple to extend this study to collect data from several sensors at once by connecting a WSN communications module with the sensor module. In the case of multiple devices, senor processing and communication can be interconnected through the addition of a wireless module for communication between sensor nodes, as shown in Figure 2. For example, in another test of an indoor garage, the authors applied a wireless module RFM70 is a transmitter /receiver that operate at a frequency of 2.4GHz. The module has low power consumption, which is 23 mA when it is used as a transmitter and 18 mA as a receiver. It can be powered by supply from 1.9V to 3.6V, but its inputs withstand the voltage up to 5V. Consumption in standby mode of the module is only 50 A. The speed of wireless transmission of this module is 1Mbps or 2Mbps [29].

For data collection, the data were gathered from the collection node to the sink node. The use of network topology was a star and the sink node stored the gathered data to a MicroSD card for post-processing. The measured data were processed offline. In the next sections we describe the operational purpose of the logistics base, and also how the data were collected.

A. *Vestbase AS – Logistics Base*

Vestbase AS is a shipping base that offers centralized supply and logistics functions. It is the business base for over 60 companies, with hundreds of indoor and outdoor work spaces.

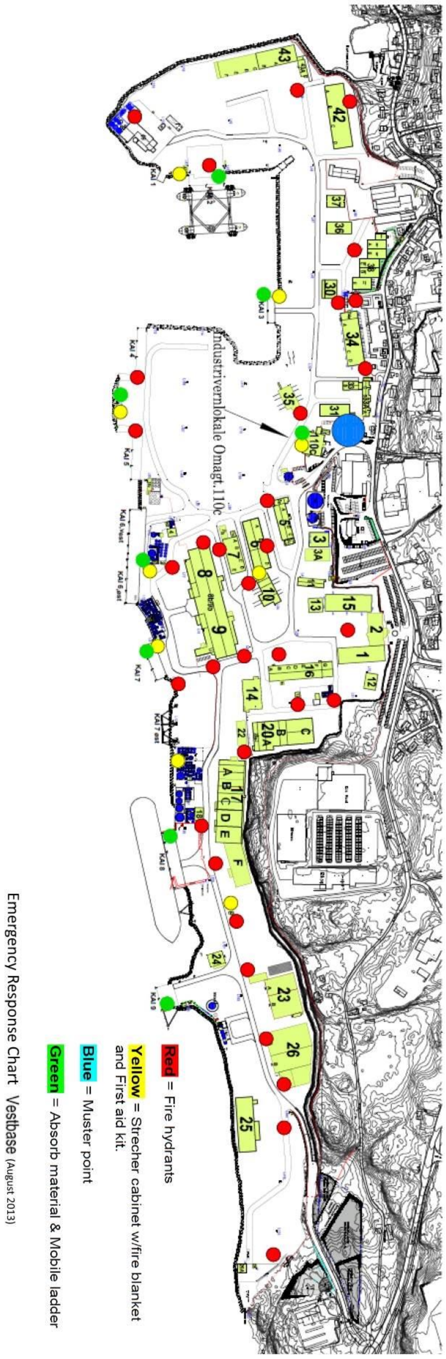

Fig. 3. Vestbase map of safety equipment [30, p.46]

The base offer a broad spectrum of services, several are listed here [31]:

- •Ship Chandler
- •Wire Spooling and Production
- •Rental of Tanks and Containers
- •Waste Handling and Tank Cleaning
- •Marine Gas Oil, LNG and Methanol
- •Dry Bulk Products
- •Welding and Fabrication Workshop
- •Subsea Maintenance Workshop
- •Subsea Maintenance Workshop

•Subsea Maintenance Workshop
•Wire Rope Assemblies, Shrouds, Eyelets, Pennants
•Machinery Workshop
•Management Agencies
•Engineering Services
•Technical Inspection and Services, including NDT
•Electro Workshop
•Victualing and Provisions
•Oil Spill Preparedness, Barriers and Booms
•Transport, Forwarding and Customs Clearance
•ISO Standards Certification
•Metal Preservation, Protection and Coatings [31].

Vestbase also facilitates the handling and storing of goods at quays and on-shore facilities, a range of mechanical services and handles transport and delivery needs. The bases overview of security and safety information and procedures is already very extensive. An example is the map of safety equipment depicted in Figure 3. Considering the diverse array of activities and building spaces on the base, monitoring air quality would be a valued addition to an HSE program.

B. *Trial for Building 11*

The WSN sensor was located in building (B.11) that is a forklift repair workshop. It was deployed from August 1st until August 15th. The data collection reported here is also reported in [32]. The sensor was placed at the side opposite to the door in building 11. It was situated in the corner of the workshop, 2 meters above the floor. We present the peak concentrations of CO2 in Table 2. Some of these can be considered "high" but are all for relatively short intervals. For example, 02.08.2016 20:46 – 20:49 is 9500 ppm. This is of level of "concern" and should only be allowed for short periods. The time intervals are shown in minutes in Table II.

TABLE II. PEAK OCCURANCES OF HIGHER CONCENTRATION OF CO2

Occurrence	*Interval (min)*	*Concentration*
01.08.2016 15:19 – 15:21	:02	> 4 000 ppm
02.08.2016 15:40 – 15:41	:01	> 3 500 ppm
02.08.2016 19:20 – 19:22	:02	> 4 500 ppm
02.08.2016 20:16 – 20:20	:04	> 6 000 ppm
02.08.2016 20:46 – 20:49	:03	> 9 500 ppm
03.08.2016 08:42 – 12:58	3:04	500 – 4 200 ppm
03.08.2016 13:28 – 13:48	:20	> 2 000 ppm
03.08.2016 18:11 – 18:46	:35	3 500 ppm – 6 500 ppm
04.08.2016 10:23 – 10:27	:04	> 1 500 ppm
05.08.2016 10:32 – 10:33	:01	> 8 500 ppm
05.08.2016 13:42 – 13:45	:03	> 2 500 ppm
05.08.2016 14:59 – 15:01	:02	> 1 500 ppm
07.08.2016 13:37 – 13:50	:13	1 500 – 2 500 ppm
07.08.2016 14:17 – 14:29	:12	> 1 500 ppm
07.08.2016 17:35	<:01	> 2 500 ppm
07.08.2016 19:15	<:01	> 2 000 ppm
08.08.2016 08:48 – 08:49	:01	> 1 000 ppm
08.08.2016 09:43 – 09:45	:02	1 500 – 2 000 ppm
08.08.2016 11:07 – 11:10	:03	900 – 1 000 ppm
08.08.2016 13:06 – 13:08	:02	900 – 1 000 ppm
08.08.2016 19:30 – 19:33	:03	> 1 000 ppm
09.08.2016 10:57 – 11:01	:02	6 000 – 10 000 ppm
09.08.2016 13:32	<:01	> 8 000 ppm
10.08.2016 10:14 – 10:21	:07	> 1 000 ppm
10.08.2016 11:39 – 11:45	:06	> 1 000 ppm
10.08.2016 13:14 – 13:26	:12	2 000 – 3 500 ppm
10.08.2016 14:35 – 14:38	:03	> 1 000 ppm
11.08.2016 09:35 – 10:27	:52	1 000 – 2 000 ppm
11.08.2016 18:32 – 19:07	:35	1 500 – 3 000 ppm
11.08.2016 19:48 – 20:34	:46	3 000 – 4 600 ppm
11.08.2016 20:54 – 20:57	:03	> 3 000 ppm
12.08.2016 13:41	<:01	> 6 000 ppm
12.08.2016 15:18 – 15:23	:05	2 500 – 3 500 ppm
14.08.2016 18:46 – 18:48	:02	> 1 000 ppm
14.08.2016 19:47 – 19:56	:09	> 1 000 ppm

The average CO2 concentration values per day are shown are in Figure 4. The gathered data were also divided into subsets (Figure 5) where each of them represents two weeks period of the measurement. The data were recorded from August 1st - 13:30, so the first day log starts from this time. As the results show, the CO2 level was changing rapidly and each day has unique behaviour. The CO2 level represented does not vary significantly during the night (from 0:00 until 8:00), so for the precision preserving, this period is excluded from the representation where each day is visualized separately. From the gathered data the trend of CO2 level in the workshop was produced. It is obvious that there is a lot of activity going on, mainly during the working week. In spite of this fact, the peak values do not occur so often and are still within an acceptable limit (Table 2). Since the workshop has good ventilation, the occasional peaks of CO2 concentration do not significantly affect the air quality in long term. As the workers say, they have usually closed the main gate. This can be reason, why the CO2 levels decreasing slightly for example on Thursday 11.8., after 8 PM when the personnel left and the same situation happened on Friday 12.8 and few more (not so significant) on other days. Other high spikes might be caused by moving the machines (forklift trucks) in and out from the workshop or by starting an engine while the service was provided. Greater details of CO2 levels, temperature and relative humidity at 5 minute intervals were collected, but room does not permit their presentation here.

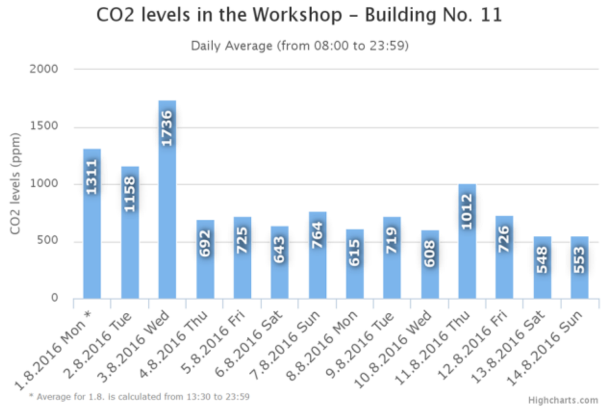

Fig. 4. Daily average of CO2 levels in two weeks

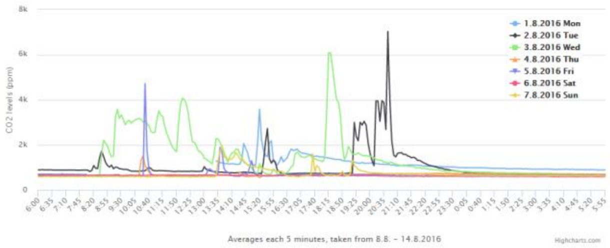

Fig. 5. Overview of CO2 levels for two weeks 1.8.2016 -14.8.2016

The average CO2 concentration values per day are shown in Figure 4. Figure 6 shows the temperature and humidity overview during the measurement period.

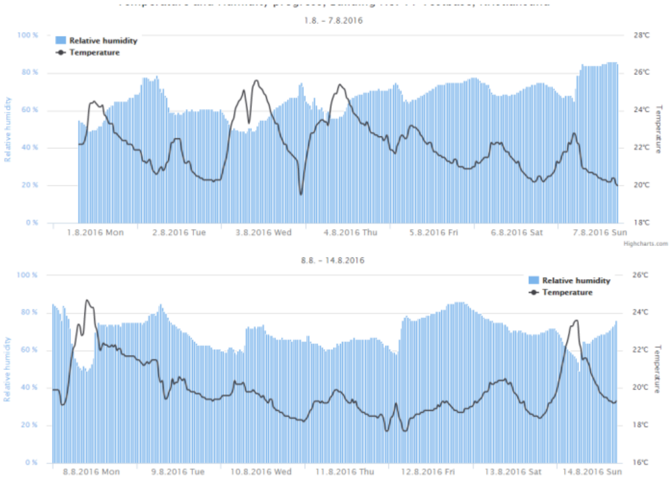

Fig. 6. Overview of temperature and relative humidity 1.8.2016 -14.8.2016

C. Trial for Building 43F

Building 43F is used for cleaning pipes with high pressure water, a process that can produce excess CO2. The data collection reported here is also reported in [32]. The measuring unit was deployed from August 24th until August 30th. The sensor was placed at the side opposite to the door in building 43F. It was situated in the corner of the workshop, 2.5 meters above the floor. The gathered data are shown in the Figure 7 which represents one week period of the measurement. In Table III the data shows there is a concentration above the level of 2 000 ppm almost for 24 hours. It is believed that the cause of increasing the CO2 levels could be closing the door after the end of the shift.

TABLE III. PEAK OCCURANCES OF HIGHER CONCENTRATION OF CO2

Occurrence	*Concentration*
26.08.2016 02:20 – 06:50	> 2 000 ppm
26.08.2016 06:55 – 08:05	> 2 500 ppm
27.08.2016 14:20 – 28.08.2016 12:10	> 2 000 ppm
29.08.2016 15:50	> 1 000 ppm
30.08.2016 10:05	> 2 000 ppm

From the gathered data the trend of CO2 level in the workplace was produced. It is obvious that there is an activity going on, mainly during the working week. In spite of this fact, the peak values do not occur so often and are still within an acceptable limit (see Table 3). Since the warehouse has good ventilation, the occasional peaks of CO2 concentration do not affect the air quality in long term significantly. In the following Figure 7, the average CO2 concentration values per day are shown. Figure 8 shows the CO2 levels per each day. Figure 9 and 10 show 2 days with the highest average occurring during the weekend. It could be that the doors were closed and the ventilation was off at that time. Figure 11 shows the temperature and humidity overview during the measurement period.

In brief the results show in Figures 9 and 10 that the CO2 level was not changing rapidly but each day had unique behaviour. The CO2 level represented does not vary significantly except for two periods: from Thursday (2 to 4 PM) and Sunday (12 AM to 2 PM).

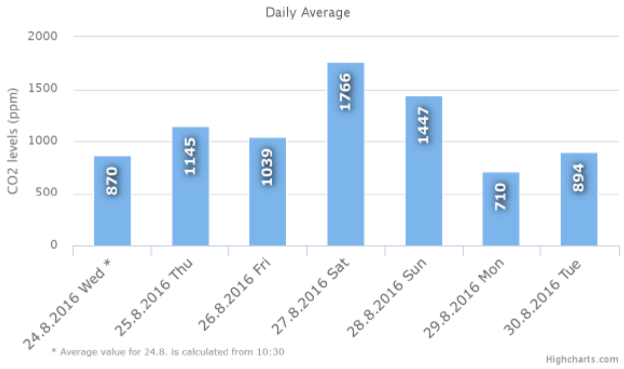

Fig. 7. Daily Averages CO2 levels in one week

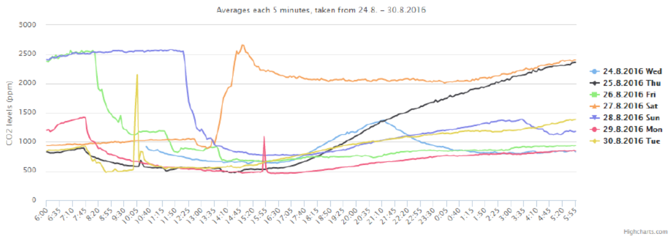

Fig. 8. Overview of CO_2 levels for the week 24.8. – 30.8. 2016

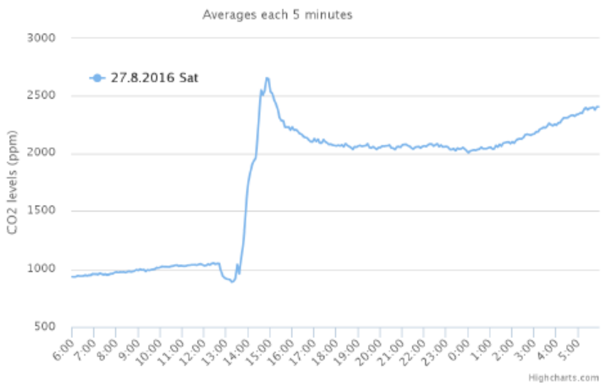

Fig. 9. CO_2 levels progress during the day – 27.8.2016

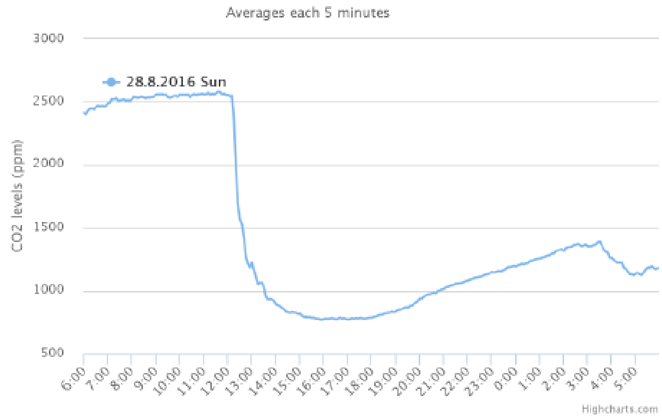

Fig. 10. CO_2 levels progress during the day – 28.8.2016

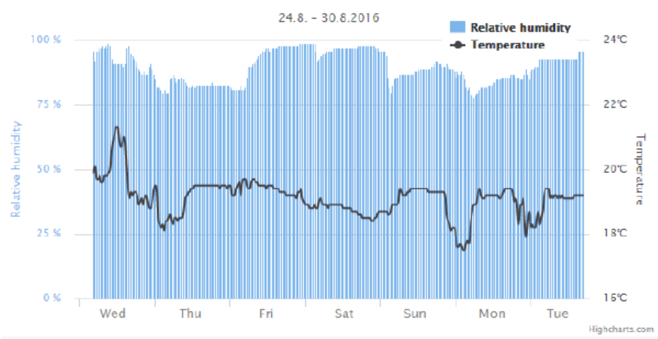

Fig. 11. Temperature and humidity overview of the week

IV. DISCUSSION

In both case trials it was shown that the CO_2 levels were within acceptable limits, meaning that workers were not exposed to more than 5000 ppm for an 8-hour workday. Further, although there were a few spikes of CO_2 as reported in Table 2, these were limited to a few minutes' intervals and were considered dangerous. In this study we have gained knowledge of the air quality through analysis of the collected data. In particular, it can be confirmed that the work environment was operated within the acceptable range according the industry safety standards. The analytical findings can associate particular spikes in CO_2 measures with particular work activities (e.g. such as moving a forklift). This type of information could be useful to management in spacing activities during the work day or work week. The findings also suggest that the communication of information (such as when spikes occur) is critical to work planning. Communication is dependent on the state of systemic integration in the logistics supply base network, both regarding information system integration within the supply base, but also regarding sharing this information to substantiate that the supply base flows safe operations practices to its multiple networked stakeholders.

We recognize the challenge of graphical presentation of the data in a meaningful way is normally a big challenge for BD analytics. In these case trials, however, the challenge does not appear to be very great because we are limiting the scenario to collecting data from one sensor. So the volume is limited and monitoring of only three internal climate factors suggests limited variety. The speed of incoming data, the velocity, is also pre-determined, as we are measuring climate factors at five minute intervals. The challenges of volume and variety are most relevant to discuss here. These factors are somewhat related. As we increase variety of measures, we also increase the volume of BD to be considered in decision making.

For data sets (B.11 and B.43F) we use static images and threshold axis labels to indicate when attention is needed. However, such approach should be scalable to measure multiple work spaces (e.g. 100s of workspaces, imagine cubicles on a ship), to be able to signal when thresholds are exceeded and should have the ability to identify the location the rooms that have problems. The visualization in a scaled up case, could have displays for each monitored location in separate PC windows. Alternatively, the display could be shown only for rooms that exceeded thresholds. While the measures would continue to come in and be processed, the display tool could be programmed to only open the display when these exceptions occur.

A limitation of this study is that the air quality factors measured do not reflect the complexity of the real work environment. In the workshop environment we are only measuring one gas (CO_2). Alternatively, in other industrial settings dangerous gases may need to be measured. For example, in more complex industrial cases, with a greater variety of data (e.g. hydrogen sulphide – H_2S, carbon monoxide – CO, etc.), the visualization system would need to be designed to provide real-time presentation of data that would indicate degree or urgency and warnings that may be needed to make more timely decisions.

The graphical presentations used in our study do leverage the ability of management to make sense of the volume of data that are collected from the WSN sensors.

In our presentation of data we overlapped data collected across all the sampled 24 hour periods. This presentation can be used to look at difference between quality measures at time intervals across days of the week. The application of this approach can be useful in this case. For example, it could be imagined that in an industrial setting that one objective might be to associate air quality with special activities (e.g. washing pipes on Tuesdays). Spacing the number of activities may be based on the know impact on the air quality.

Lastly, we highlight that in the case studies the time-frame for decision making about air quality in the workshop locations took place the week after a data-collection period was completed because the trial settings are not in high risk work settings. However, in a larger scale application the interpretation of the BD can result in a decision to change periods of worker activities or settings on the ventilation systems. Also, in high risk area, the time-frame for decision making would need to be shorter, perhaps must be made within minutes. The analysis made in a short time-frame can result in a more immediate decision to evacuate a building.

V. CONCLUDING REMARKS

In summary of our findings, this paper presented an automated approach for monitoring and visualization of air quality using air quality data as collected with WSN technologies in two workshops at an on-shore logistics shipping base. This monitoring is dependent on information connectivity and produces data that may be characterised as "big". This case study has shown that increased industrial activities in a confined workspace can have impact on CO_2 levels. More importantly however, autonomous technologies such as WSN CO_2 sensors can be applied with a BD analytic approach for monitoring a healthy and safe work environment. It is relatively straightforward to extend this study to more complex environments using WSN communications technologies. We have further discussed alternative information visualization approaches are needed for different more urgent circumstances. In cases where more factors (variety) of data are needed, the visualization system may need to "select" to present the most critical data that exceeds thresholds, and down prioritize the presentation of other data.

The main contribution of this research is that it seeks to empirically ground and understand what are still weak notions regarding generating and using complex data in relation to air quality monitoring; a specific type of industrial functionality in the unique setting of a logistics supply base supporting offshore petroleum exploration and production activities. We find that this implies the need to explore data complexity associated with continuous monitoring of diverse work environments that can provide a stream of meaningful actionable information. In such a context the richness of data is primarily associated with monitoring transformations registered by the monitoring equipment and the use of this information. This renders actually connectivity with the stream of actionable information more important than the bigness of data (e.g. its volume, velocity, variety, etc.). We may conclude in this case study that the data is not all that "big" and so transformation tools (e.g. data mining) is not a key part of the analytics. The lesson learned from the case study is that the usefulness of the retrieved data is established by its transformation into readable forms through visualization of that information. Connectivity is a main facilitator of using this data, and points to IIoT as a more powerful analytical approach than BD directing focus to show that data is created and translated into information. Here BD, viewed as a research approach, in the form of analytics, couples different information sources to render information more viable for managerial sense making (decisions). BD is in this case rendered a tool in transforming complex data into information. The value of information is associated with factors of timely retrieval and visual communication and in this case, can be integrated with a Lean production system. Based on our experience in building the visual analytics prototype for a logistics shipping base [33][34]. We intend to develop more advanced VA facilities for workplace safety.

As mentioned in Section I, a smart closed-loop system for work spaces safety is technologically feasible given the fast advancement of IIoT technologies, especially for actuating devices. For example, in other work spaces of the same on-shore logistics facility workers can be exposed to sharp but brief rises of other hazardous gases. In actual cases where those areas are not receiving proper ventilation, it would be much more responsive to have actuators that are capable to automatically activate necessary counter-measures (notifying human at the same time). Note that keeping human in the loop is necessary for safety reasons. For the smart closed-loop system to work properly, real-time decision support and interactive visualization are essential. In conclusion, we suggest that the approach combining IIoT and active actuators would support more proactive controls. As such it would be possible for management to generate a smarter and safer workplace.

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References

[1] Engelseth, P. and Pettersen, T.M. (2016), Agent-Based Modelling of Offshore Upstream Petroleum Logistics, International Journal of Design & Nature and Ecodynamics, 11(4): 635-643.

[2] Strange, R. and Zucchella, A. (2017) "Industry 4.0, global value chains and international business", Multinational Business Review, Vol. 25 Issue: 3, pp.174-184.

[3] Essex, D., "Manufacturing IoT takes the lead on connecting devices," Tech-Target, Essential Guide, Online Dec. 7, 2015, http://internetofthingsagenda.techtarget.com/feature/Manufacturing-IoT-takes-the-lead-on-connecting-devices, accessed Jan. 30, 2018.

[4] ECC-OSH (1989). Directive 89/391/EEC - OSH "Framework Directive on Safety and Health at Work", last ammendment 2008, online at: https://osha.europa.eu/en/legislation/directives/the-osh-framework-directive/1 Accessed: Jan. 30, 2018.

[5] Robb, D., "Internet of Things adds intelligence to supply chain," Enterprise Apps Today, Dec. 8, 2015, http://www.enterpriseappstoday.com/supply-chain-management/internet-of-things-adds-intelligence-to-supply-chain-1.html, accessed Jan. 30, 2018.

[6] Engelseth, P. (2017), Reverse Logistics as a Complex System - A Case Study of Waste Management in the Norwegian Offshore Petroleum Industry, International Journal of Design and Nature & Ecodynamics, Vol.12, No.3, pp. 348-356.

[7] D'Souza, D.E. Williams, F.P. (2000), Toward a taxonomy of manufacturing flexibility dimensions, Journal of Operations Management, Vol. 18, Issue 5, August 2000, Pages 577-593

[8] Wycisk, C., McKelvey, B. and Hülsmann, M. (2008), "Smart parts" supply networks as complex adaptive systems: analysis and implications, International Journal of Physical Distribution & Logistics Management, Volume: 38 Issue: 2, pp. pp.108-125

[9] Heiselberg, P.K. (Ed.) (2016). CLIMA 2016 – proceedings of the 12th REHVA World Congress: volume 7, Aalborg: Aalborg University, Department of Civil Engineering. Accessed from vbn.aau.dk on July, 19, 2016.

[10] Norbäck, D., Nordström K., and Zhao, Z. (2013). "Carbon dioxide (CO2) demand-controlled ventilation in university computer classrooms and possible effects on headache, fatigue and perceived indoor environment: an intervention study" Int. Arch Occup Environ Health (2013) 86:199-209.

[11] Skyberg, K. and Skuleberg, (2003). "Symptoms prevalence among office employees and associations to building characteristics", Indoor air 13(3) 2003, 246-252.

[12] Arbeidstilsynet, (2012). Veiledning om klima og luftkvalitet på arbeidsplassen. Veiledning, best nr. 444 (2012).

[13] Mycoteam, (2015) "Kontroll av inneklima I utvalgte rom" Report 2015 (ref: 201504051), 6. mai.2015.

[14] Solberg, K. V., Cao, G., Alonso, M. J., and Burud J. P. (2016) "A Field Study of Indoor Climate in an Energy Efficient Building in Norway" In Heiselberg, P. K. (Ed.) (2016). CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 7. Aalborg: Aalborg University, Department of Civil Engineering.

[15] Shahzad, S. S., Brennan, J., Theodossopoulos, D. Hughes, B., Calautit, J. K. (2015) "Energy efficiency and user comfort in the workplace:Norwegian cellular vs. British open plan workplaces", Energy Procedia 75, 807–812.

[16] Vasaila (2011). "Know the Risks – Work Safely with CO2", Application Note, Ref. B211122EN-A. Vaisala 2011, Online http://www.vaisala.fi/Vaisala%20Documents/Application%20notes/CEN-BAU-Work-Safety-CO2-Application-note-B211122EN-A-LOW-v3.pdf Accessed 23 April 2017.

[17] Garcia-Romeo D., Fuentes H., Medrano N., Calvo B., Martinez P. A., Azcona C., (2012). A NDIR-based CO2 monitor system for wireless sensor networks, Circuits and Systems (LASCAS), 2012 IEEE Third Latin American Symposium on , vol., no., pp.1,4, Feb. 29 2012-March 2 2012

[18] Kwon, J., Ahn, G., Kim, G., Kim, C., Kim, H. (2009). A study on NDIR-based CO2 Sensor to apply Remote Air Quality Monitoring System, ICROS-SICE International Joint Conference 2009

[19] Futurlec, (2016) MQ-135 datasheet, https://www.futurlec.com/Datasheet/Sensor/MQ-135.pdf

[20] Laney, D. (2001). "Application Delivery Strategies", META Group, META Delta, File 949, 6 February.

[21] Rozados, I.V. and Tjahjono, B., 2014. Big Data Analytics in Supply Chain Management: Trends and Related Research, 6th International Conference on Operations and Supply Chain Management, Bali, 2014.

[22] Hilbert, M. (2016). Big Data for Development: A Review of Promises and Challenges, Development Policy Review, 34(1), 135-174.

[23] Kamran, A and Haq, S.U., 2013. Visualizations and analytics for supply chains, IBM developer Works, Technical report Feb. 26th, Accessed 03.02.14 at: http://www.ibm.com/developerworks/library/ba-visualizationsanalytics/

[24] Keim, D., Andrienko, G., Fekete, J-D., Görg, C., Kohlhammer, J. and Melançon, G. (2008), "Visual analytics: Definition, Process, and Challenges," in Information Visualization, ser. LNCS, vol. 4950. Springer, 2008, pp. 154–175.

[25] Fekete, J.-D., Van Wijk, J. J., Stasko, J. T. and North, C. "The value of information visualization (2008)," in Information Visualization, ser. LNCS, vol. 4950. Springer, 2008, pp. 154–175.

[26] Lu, X., Ota, K. and Dong, M. (2017). Predicting Transportation Carbon Emissions with Urban Big Data. T-SUSC, IEEE Xplore Digital Library 2(4): 333-344.

[27] Dong, M., Ota, K. and Liu, A. (2016). RMER: Reliable and Energy-Efficient Data Collection for Large-Scale Wireless Sensor Networks. IEEE Internet of Things ournal 3(4): 511-519.

[28] Hu, Y., Dong, M. and Ota, K. (2016). Mobile Target Detection in Wireless Sensor Networks With Adjustable Sensing Frequency. IEEE Systems Journal 10(3): 1160-1171.

[29] Žalman, R., Olešnaníková, V., Šev˘cík, P. and Šarafín, P. (2015). "Monitoring of CO2 Amount in Closed Objects via WSN", Proceedings of the Federated Conference on Computer Science and Information Systems, IEEE, ACSIS, Vol. 5 pp. 1257-1260.

[30] VESTBASE (2017). Marinetime Instruction- Terminal Information Booklet – Vestbase AS, Ref. Doc. NSGM-275775254-838, 22.06.2017, Online. Accessed: Nov. 2, 2017, https://www.vestbase.com/images/dokumenter/pdf/Terminal-Information-Booklet-english.pdf

[31] VESTBASE AS (2017). Cluster-Vestbase. Online. https://www.vestbase.com/cluster-vestbase/general Accessed: Nov. 2, 2017.

[32] Molka-Danielsen, J., Engelseth, P., Olešnaníková, V., Šarafín, P. and Žalman, R. (2017). "Big Data Analytics for Air Quality Monitoring at a Logistics Shipping Base via Autonomous Wireless Sensor Network Technologies", Proceeding of the 2017 5th International Conference on Enterprise Systems - Industrial Digitalization by Enterprise Systems, Eds: Pang, Z., Li, L. and Li, G. IEEE Computer Society, CPS, Lost Alamitos CA, ISBN-13: 978-1-5386-0936-1 and ISSN 2572-6609, pp. 38-45.

[33] Wang, H., Zhuge, X., Strazdins, G., Wei, Z., Li, G. and Zhang, H. (2016), "Data Integration and Visualisation for Demanding Marine Operations," in Proc. MTS/IEEE OCEANS 2016, Shanghai, China, 2016.

[34] Zhuge, X., Wang, H., and Strazdins, G. (2016). "Evaluating the Data Visualization for Demanding Marine Operations". Techno-Ocean Conference 2016. Kobe, Japan, IEEE Press, Oct. 2016, Pages pp. 471-477.