Automation and Control of DIA Transportation Tunnel

Ahmed O. Abdul Salam
Roads Lighting and Traffic Signals, Roads Department, Roads and Transport Authority (RTA), P. O. Box: 118899, Dubai, UAE. Email: AhmedAbdulsalam@rta.ae, Tel.: 04-2065868, Fax: 04-2065663

Abstract—This paper discusses the full automation and control features of electromechanical systems and ITS (Intelligent Transportation Systems) in Dubai International Airport (DIA) tunnel. The self-automation and control using SCADA (Supervisory Control and Data Acquisition) technology for data processing enhances the intelligence level of DIA tunnel. The intelligent components in this tunnel designed and constructed in a redundant manner to increase systems reliability and hence the overall safety improved. The sophistication of DIA tunnel and the variety of equipments places this tunnel on top of intelligence and safety levels among few others in the world and surely the first of its kind in the region.

I. INTRODUCTION

The intercity DIA tunnel is about 1.5km long and consists of two main tunnel tubes, with four lanes per direction, primarily intended to ease the traffic flow situation between Dubai and Sharjah. This tunnel considered as an essential hub that positively influences the rapidly evolving economy in Dubai and symbolizes a modern traffic concept in the entire region. The complete tunnel facilities installed with fully automated and centralized electromechanical services to monitor and control the systems performance using SCADA technology. The installation of services carried out in accordance with the governing international standards and regulations. Equipments for traffic management were to maintain a continuous flow of traffic information to the operators to help making critical decisions in emergencies like accidents or cars stopping. All these modern applications revolutionized the concept of intelligent tunnels and set forward a shining example for the first time in the region to achieve highest levels of motorist’s safety. The entire tunnel is a one piece of fully automated industrial entity that runs itself by itself. The intervention of the operators is to keep close eyes on screen events and video wall images and to select suitable emergency plans once required. These emergency plans were developed and saved in the system and exhibited on screens when an incident occurred.

II. SCADA FOR ELECTROMECHANICAL AND TRAFFIC MANAGEMENT SYSTEMS

SCADA systems are widely used for industrial processes. Among many applications, SCADA found in metro operation, power generation and distribution, chemistry and critical experimental physics like nuclear fusion [1-5]. This wide variety of SCADA applications is substantiated to its rich content of multiple developing tools and functionalities such as communications, interfacing, scalability, redundancy, trending, access control, alarm handling, logging and archiving, report generation, automation and object handling and configuration.

The SCADA system of DIA tunnel built with a minimum spare capacity of 20% for hardware and minimum of 50% for software in terms of data points and volume. The system has a modular design and further expansions can be readily realized in future. The DIA tunnel control system has been designed to provide a high level of data and control integration, covering each item of plant equipment and the various specialist tunnel support systems. This integration is also evident with reference to the plant screen layouts and operational methodologies, whilst satisfying the need to keep particular systems’ components only available for authorized and experienced individuals for safety and security purposes. The traffic control center (TCC) equipments room constitutes the following pairs of hot redundant servers, and Fig. 1 depicts the building components of SCADA architecture:

- SCADA
- Network
- AID (Advanced Incident Detection)
- Access control
- Web applications
- VMS and LUS signs

The servers’ scheme built up using two redundant high-speed switches and looping worked out using normal networking cables. The industrial Ethernet established using master programmable logic controllers (PLCs) and redundant multimode (MM) fiber optic (FO) cables in a ring network configuration. These PLCs are characterized to have better data handling and performance capacity compared to those in the cabinets of field devices and subsystems. Approximately 16,000 analog and digital data points interrogated and processed by these powerful PLCs. The connectivity between master PLCs and FO cables implemented using redundant optical switch modules (OSM) with protection features. In addition, there are dedicated SCADA operators’ workstations and terminals for variable message signs (VMS) and lane use signs (LUS) and access control applications. Printers connected to the servers’ network for alarms and events printout records and other general purposes. The TCC servers and operators rooms are shown in Fig. 2.
Two GSM (Global System for Mobile communications) devices connected to SCADA servers to send SMS (Short Message Services) to different groups of people upon certain events in the tunnel. For example, major events like fibrolaser alarm for fire in tunnel or tunnel closure communicated to superior RTA personnel as depicted in Fig. 3.

Other critical events also sent via the same approach to highlight critical activities in the tunnel that entail immediate technical intervention or to inform about maintenance requirement of a malfunction device or system component.

Operators can monitor all sections and facilities of the entire tunnel by observing the video wall screen in the control room as shown above. This screen consists of 4x4 video wall cubes connected directly to SCADA servers through their matrix controller. The operator can manually switch among different cameras installed in the tunnel or in other defined critical locations. An automation process worked out to switch particular camera in event location on system screen to attract operators’ attention. Among many cases, a fire in one section will switch the nearest CCTV in that location on screen or in case of car stops or pedestrian walking in tunnel, or if there is a security access breach. All major cases are associated with different plans and mapped into a pattern of responses schedules stored in the memory of main SCADA servers and properly exhibited to the users whenever needed or automatically triggered upon sudden cause.

Generally, the integration of SCADA and other servers will provide the following functions, which will be briefly illustrated in the following context:

- Communications
- Power distribution
- Lighting
- Ventilation
- CCTV monitoring
- Traffic management
- Fire system
- Drainage
- Access management
- Alarms and trends

A User Interface

The SCADA screen interfaces have been designed to be user friendly and covering all operational aspects of each individual application. Intuitive graphical displays created by working closely with the client and fulfilling the operators’ requirement to be self guided and easily manageable. The interface is divided into simplified single screen views for each application with a common header and footer layout and object styles. Dynamic effects involve colors and real time figures used to show the operational condition of each subsystem.

B Communications

The SCADA interface for communications is developed to display the links status of all devices and networks in the entire control system as shown in the sample Fig. 4. Using these screens, the operator can check the redundancy of the servers, switches, FO cables, OSMs, Profibus cables, and the redundant PLCs in each cabinet for any system. The fault will be displayed either in a different color or cross sign.

C Power Distribution

Fig. 5 illustrates the functional screen of power systems in the tunnel. It is obvious from this figure the power ring feed obtained from different sources, which is quite evident that failure of any power source will not disturb the whole services in tunnel. From the same screen it is also obvious the power consumption of each substation. Clicking on each substation name will give details on the associated distribution board (DB) and motor control center (MCC) power panels. Then the operator can set circuit breakers either in remote mode or in local, manual or automatic. This actually applies to all electrical appliances of the tunnel. Tripping or fault status can also
be observed in the same manner. The SCADA program continuously monitors the state of each supply bus overriding the associated lighting, ventilation and pump demands in the event of a supply failure so as to keep only the critical loads fed by the generator or the uninterruptible power supply (UPS). The trends of electrical parameters and power consumptions also can be monitored by SCADA just like lighting and ventilation systems.

**D Lighting**

The lighting control and management system of DIA tunnel is one of the most complex and advanced system in the world. Total of 6,400 lamps are controlled and monitored in the longest road tunnel in the Middle East. The components of the system are distributed throughout the four substations and the ancillary buildings. They are linked together through a redundant FO ring network separated than SCADA network. Each of the 471 lighting circuits is controlled and monitored individually specially dedicated dimming controllers, problems are reported immediately and alarms are raised through the main control system.

When designing the system the he highest priority was given to safety and security; all systems have backup functions guaranteeing the lighting even in the worst case. As a second priority, the operational cost of the tunnel was in the foreground. The system installed will save about 25% of energy compared to traditional systems and the lamps last up to twice as long with the stabilization of the mains voltage and the dimming of the lamps.

The master lighting control station is linked to the central SCADA control system of the tunnels. From there the system can be operated and monitored. In emergencies specialized engineers can log on to the system from any where in the world, using a secured internet connection.

The SCADA provides automatic and manual control of lighting for the entire tunnel and ramps depending on the external light level and traffic conditions. This information is compiled onto dedicated lighting interface screens, on SCADA and lighting servers and on HMI terminals at each lighting cabinet in the tunnel and substations as illustrated in Fig. 6.

Lighting for the main tubes is divided into 5 primary stages. Stage 1 is night lighting and realized using fluorescent light fittings mounted on both sides of the tunnel ceiling. Stages 2 through 5 provide boost lighting via high-pressure Sodium vapor (HPSV) lamps in the portal entry and exit regions. Reference to the sun light level these HPSV are dimmed accordingly, whilst the fluorescent light is only monitored and 20% are connected to the UPS feed during emergency situations of power blackout. During fire, all lights are 100% operational with maximum illumination. The HPSV lighting stages are called Dull, Sunny, Very Sunny, and Very Very Sunny. Moreover, HPSV dimming is also related to the traffic volume as measured by detectors installed at tunnel portals and exits.

**E Ventilation**

The central SCADA system provides automatic and manual ventilation control for both the main and the ramp tunnel tubes as obvious in Fig. 7. Ventilation is automatically controlled based upon the measured values of CO concentration and visibility in steps independent for each tube. The main direction of rotation of jet fans (JFs) is in the direction of traffic flow, whereas reverse direction is opposite to the traffic flow. Worth mentioning, is that there is a built-in feature of self-interlock configured in the motor protection relay (MPR) of each JF to prevent rotation in one direction and then immediately reverse. This protection configuration is also conducted via SCADA timing procedure.

There are three modes of SCADA control for JFs prioritized as follows:
- Low: Automatic based on CO levels.
- Mid: Manual control by SCADA operator.
- High: Override and SCADA resumes full command in case of fire.

Additional local control, like any other system in the tunnel, is also possible. However, this mode of operation will override any SCADA command and visual and audio alarms will be initiated and logged into the archive file of SCADA system. When fire is detected by the Linear Heat Detector (LHD) or fibrolaser cable, then the highest priority mode of control is launched automatically by SCADA system. All previous control commands will be skipped and accordingly special sequence of operation will be started to suck the smoke away from the tunnel. For this to be valid all JFs are to be in remote and auto modes via SCADA screens.
F CCTV Monitoring

The CCTV system is linked to SCADA using OPC protocol (OLE Object linking and embedding for Process Control). This kind of software interface is required to allow SCADA to switch cameras either manually or automatically in case of predefined events. Eventually, the camera nearest to event will be displayed on the video wall. Valuable information, such as traffic volume and status, can be obtained by clicking on the cameras’ icons in SCADA screen as shown in Fig. 8.

Totally there are 103 CCTV cameras inside the tunnel, 8 PTZ (Pan/Tilt/Zoom) cameras at portals, and 4 Dome cameras in substations and 2 in the TCC building. The CCTV cameras are lined up on both tunnel sides to maintain two lanes of coverage for each unit in addition to footpath and shoulder. The CCTV cameras are of advanced technology type and can produce different feedback signals to SCADA system on video quality and smoke presence among others. The smoke detection feature is very important and adopted in some overseas tunnels [6]; however, in DIA tunnel this feature represents second priority after the prime reliance on LHD approach.

The video stream of all cameras is saved on especially dedicated digital video recorders (DVRs) that can be customized to accommodate flexible storage time as convenient. In DIA tunnel the setting of 16f/s stays for 30 days of storage period. The saved material can be retrieved at any time and updated automatically by the system.

G Traffic Management

Traffic management in DIA tunnel provides means to monitor and control the following traffic aspects per lane:

- Counting number of vehicles
- Average speed of vehicles
- Occupancy
- Vehicle headway

Monitoring attained using a special type of CCTV cameras, or called detectors, fixed with certain aiming angles and coverage area. All fixed cameras make available full coverage of entire areas inside tunnel including shoulders and footpaths. Video frames sent to AID system to extract useful information in order to facilitate two important objectives. The first objective is to give insight on traffic flow in tunnel, which displayed to operators as optional. The second objective is to assist SCADA server doing crucial decisions upon undesirable events like pedestrian crossing or car stopping. Such critical events popped up on operators’ workstations irrespective of which SCADA screen displayed at the time of event as shown in Fig. 9.

On the other hand, two types of LED signs, namely the VMS and LUS, achieve the traffic control in tunnel. Two types of VMS signs installed, the first is with one line of text display, and the second with two lines of text display as depicted in Fig. 10. Both can show Arabic and English symbols. The total number of VMS signs is 9 of single line type in tunnel and 3 of double lines type at tunnel entrances. The LUS’s counted to be 100, constructed as back-to-back pairs and interlocked using electronic means. That means if one face shows green arrow then the backside should never display green arrow or flashing yellow other than cross red conclusively.
Operators accomplish the traffic control in case of emergencies relying on predefined response plans that will be triggered automatically by SCADA system and selectable. These plans are associated with particular traffic layouts to simplify the selection task. Moreover, additional LED type fixed message signs (FMS) are also installed at the approach roads leading to tunnel entrances to display “Tunnel Close” that can be activated either to certain plan or for maintenance use. Commands sent individually to respective VMS and LUS upon selecting appropriate plan. After a preset period, the status of each VMS and LUS sign retrieved and compared with issued command and hence alarms for possible sign control failure interrogated whenever discrepancies detected. Noting that a particular plan continues to execute irrespective of errors and hence to allow operator calling for support. All signs will be blank until such errors rectified.

**H Fire System**

Two components constitute the fire system, namely the fire alarm and the fire pump stations (FPS). The fire alarm will be recognized upon detecting the status of the redundant LHD cable, manual pull stations (MPS), fire hose cabinets (FHC) and fire extinguishing cabinets (FEC) doors opening, emergency exit doors, and with less priority of CCTV smoke appearance in video. Such detection will change colors of the above elements in SCADA screen as revealed in Fig. 12. The ultimatum in DIA tunnel is solely based on LHD detection as a measure of accurate temperature increase because of fire. Other events can also be treated as tantamount to LHD, but need visual verification of the operator beforehand. The LHD in this tunnel will generate first alarm upon the temperature reaches 60°C. Second higher level alarm will be substantiated after 85°C, which is considered as a dangerous temperature value. Upon receiving fire alarm, the flasher and sounder of the control room will be set out and the bell of a dedicated telephone installed in the civil defense office will ring automatically. The CCTV cameras closest to fire will be switched on video wall automatically. When confirmed by the operator the fire brigades will be mobilized to the site and certain fire response plan to be implemented in SCADA.

**I Drainage**

There are four drainage pump stations (DPS) in DIA tunnel and each is equipped with three submersible pumps and complete pipes network and sensors. These DPS are displayed on SCADA screen as shown in Fig. 14 and the operational status of each element is indicated. All pumps are to be in auto mode to allow water discharge at any time without direct supervision by the operator. Discharge process will start based on received signals of water level. Various water levels will govern the number of pumps to be operated complying with built-in sequence of commands. Releasing particular pump of duty depends on water reduction level and active sequence. Sensors will continuously transmit analog signals for quality control aims. In case one parameter exceeds certain limit then all pumps will be stopped at once. This is to comply with restrictions of discharged water quality put in place by different authorities on ground.
J Access Management

The doors opening of FHC and FEC and emergency exit doors will contribute to the process of fire alarm. This is true as shown in Fig. 15 since the opening can only be arranged through proper settings in the access management program and violation of which interpreted as a breach or indication of serious event. All the above doors and DPS and substations are provided with proximity switch for access control and card readers. The access privilege for any door to reach certain facility is only granted after being programmed in the access control server. Time period and dates for such access also can be adjusted as appropriate. In the same manner, lost cards containing such access permission would entail cancellation from the same program on the server.

K Alarms and Trends

The SCADA system has been developed to register all activities in the tunnel and to print each event using line printer. Alarms and events log browser permits selective examination of any aspect of tunnel operation. Alarms are classified based on their level of importance and impact on tunnel performance and operation. Red alarms represent highest level like fire or car accidents, which means car stopping. Green alarms come in second priority and have something to do with equipment condition or occurrence of other events. Black colored alarms stand for clearance of that event. The alarm and event log screen is so specific by having enough information about the alarm source and location and whether being active or cleared as shown in Fig. 16. On the other hand, user configurable historical trends can be generated for any analog data point processed by SCADA server. This can happen by using the built-in trending tools of SCADA to plot over time as shown in Fig. 17, which is taken for lighting system. Particular portions can be verified by managing the plot area. Trends are useful in the general performance evaluation of all systems’ components and accordingly to make relevant plans and decisions.

III. CONCLUSIONS

The DIA tunnel opened on 30th June 2005 and since that date has attracted equal attention of both residents and visitors. The electromechanical and control systems of this tunnel are one of the most technically advanced and demanding projects in the region. The RTA has precisely invested in this tunnel in terms of equipments proliferation and personnel expertise. The prime objective behind all commitments is to provide end users with a final product of high safety standards and adequate circumvent of daily traffic problems.

The safety measures of DIA tunnel are conspicuous in terms of the following features:
• Wide range of complex equipment supplied by well-established manufacturers far exceeding the average requirement for tunnel safety.

• Extensive integration of modern technologies from various sources for a wide range of specialized subsystems (SCADA, CCTV, traffic monitoring, signs, fire detection, lighting, etc.)

• High level of redundancy, duality, and backup systems employed to ensure uninterrupted system availability substantiated by spending extensive time to evaluate rigorously the full tunnel operation under severe conditions while conducting test and commissioning procedures.

• Regular training programs for tunnel operators and technical staff and update of safety mandate and practices for continuous improvements.

Finally, it should not go without saying that the more intelligence put into transportation roads and tunnels, the better safety levels achieved.

ACKNOWLEDGMENT

The author would like to acknowledge the support of HE Mattar Al Tayer (Chairman of the Board and Chief Executive Officer of the Roads and Transport Authority in Dubai) and Ms. Maitha Bin Adi (Chief Executive Officer of the Traffic and Roads Agency) during the construction phases of this project and without which this project would never come true. Acknowledgment also extended to all involved in the tunnel project, including colleagues, consultant, and contractors.

REFERENCES


