COMMISIONING OF TUNNELS

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ABSTRACT

Commissioning starts with approval of design documents, and ends with user acceptance test. In between is FAT and SAT. Planning must prepare for confirmation of fulfilment. The main success factor is that it is possible to identify and verify all demands. SAT must be planned and performed by the owner himself or someone representing him, and should not be left to the contractor

Keywords: Factory Acceptance Test, Site Acceptance Test, commissioning

1. INTRODUCTION

This paper is intended to help tunnel operators to minimize problems during commissioning and is primarily a field report, based on 27 years of practical and personal experience.

The contract and close coordination with the planner or operator before and during implementation are essential for smooth commissioning. In this way, a lengthy troubleshooting and incorrect product selection can be minimized. Some examples of ambiguities, wrong decisions and possible solutions are listed and described in more detail below. The public road authority defines the following test for a tunnel. FAT (Factory acceptance test), EET (Contractor's verification of delivered system), SAT (tunnel owner test before acceptance of delivery, or Site Acceptance Test) and UAT (Road traffic central confirmation that they can take supervise the tunnel). UAT is the last test before request for safety approval.

2. AUTOMATION AND SAFETY EQIPMENT DESIGN FROM CONSULTANT

2.1. Hardware

There are different approaches toward the design of an automatic system. Two main "schools" exist: Centralized software and decentralized software.

2.2. Centralized software

All software is located in one computer, of course with a hot backup. The benefit is that you only have one place to connect to adjust the software, and it is easy and cheap to make as simulator for testing and training of operators monitoring the tunnel. The drawback is that everything is running in the same computer, and an error in communication could have drastically impacts on safety. And the actual PLC (Programmable Logical Controller) able to do the job is very expensive.

Since one PLC is to monitor everything, scan time might be in seconds, and not milliseconds.

2.3. Decentralized software

The main focus is that the software should be performed as close to the equipment as practical. For example, the software controlling a barrier must be performed in the local control cabinet to satisfy safety regulations for the machine. Drawback, if too much is decentralised it is difficult and more expensive to make a good simulator. Decision of many small PLC, or RIO (Remote In Out unit for signals, connected to PLS by network) should be made during design, not by supplier. It affects demands for software and descriptions for how to avoid unnecessary alarms.

2.4. Demands for Software from consultant.

Very often the designers / planners do not clearly define the requirements but refer to standard documents. However, general documents are almost never meaningful enough to map all specifications in detail. The planner should therefore endeavour to identify all requirements in the descriptions, as only these can then be checked. It is important that all demands can individually referred to as demand number x.y.z, and that you know how to test it. Examples for can be found in ref 1.

3. COMMISSIONING OF THE TUNNELS, GENERAL EXPERIENCE

3.1. Design documents

<u>The work of commissioning starts when you approve the design documents for installation.</u>

If these consist primarily of references to standards, many details stay unclear. Here you need to ask the designer / planner for detailed specifications and information. This problem shall be explained below, based on the requirements for the emergency call centre.

3.2. Emergency control panel

The standard gives limited number of commands for the panel.

Command Close tunnel: This command closes the tunnel. Red stop signals turn on, all associated speed and traffic regulating signs are activated. Escape lights are activated. Other lights in the tunnel are lit and the barrier is lowered after the agreed time regarding, among other things, speed limits and stop distances.

Back to normal: The command opens the tunnel. Boom raised, red stop signal Extinguishing and traffic control signs return to their normal position. Lights and fans are set in "Normal" and escape lights go out. The tunnel is now back to normal operation with VTS as Monitors. Lamp test: Functional test of the lamps in the panel.

During Site Acceptance Test (SAT) this rarely works satisfactorily.

If the tunnel is to be closed, but the barrier is set to manual opening in the local control, first problems can arise. Should the barrier be set from manual to automatic and then close immediately or is this procedure incorrect? If subsequent changes are necessary, the contractor will ask: 'Where in the contract does it say so?'. Last observed during SAT Ryggedalstunnel

The consultant should deliver a drawing of the emergency control panel and a detailed functional description.

For example, like this:

If it is a reset of the PLC, then the emergency tableau must be put into automatic response.

If the push button "close the tunnel" is pressed, the tunnel must close for traffic, and status word for open/close tunnel must show that the command was given from emergency control panel. The button must activate all the same procedures as if the commando was given by the operator.

If the button for "return to automatic" is pressed, then it must be written in detail what should happen. Do you regard "return to automatic" as a command to "open the tunnel", or just as a command that you give away control. This must be described for the contractor. Otherwise, there is a 50% chance that it is wrong.

3.3. Factory Acceptance test (FAT)

It is important to do a thorough FAT, in several stages. The supplier will normally write the test procedures for FAT for each part to test. The design documents must contain demands for FAT, and for minimum testing of FAT. Any deviation detected at this project stage / during FAT can easily be fixed without significant additional costs.

3.4. Barriers

For a barrier normally current loops are used to detect if a vehicle is blocking the barrier to close. Some of the current loop detector units have a default setting where detection fades out after approximately five minutes. If it has this setting activated, the barrier will come down on a car that stopped below the barrier after 5 minutes. A demand for complete setup of barrier with control cabinet connected all the way to Scada during Factory Acceptance Test (FAT) will enable you to discover this error at an early stage. But you still must test it during SAT.

If the light on the barrier fails, you would like to have an error message to maintenance. Then you must test it. In the control cabinet, disconnect the $+48V_{dc}$, and half the time, no error message received. If you disconnect ground ($0V_{dc}$) nearly never an error message is received. It will not work, and the operator does not know that it is not working.

Is it possible to close the barrier before, or without a red light on? Did you test this? The juridical closing of the tunnel is the red light. Not even manually, it is legal to close the barrier without a red light on Experience shows us that this is not always safety applied.
Then we have the standard status word for a barrier, showed in Table 1. It of course exists a defined command word as well.

Table 1: status word for a barrier

		Description	
0	1	Barrier open	
1	2	Barrier closed	
2	4	Fault on barrier	Barrier has no fault
3	8	Vehicle preventing to clos	No vehicle
4	16	Alarm from vehicle under barrier blocked	Not blocked
5	32	Fault message blocked	Fault message not blocked
6	64	Directly control from road traffic central (VTS)	Controlled by automatic response or in local control cabinet
7	128	Controlled by local control cabinet	Controlled by automatic response or in from VTS
8	256	Faulty current loop	Current loop working
9	512	Error message fault current loop blocked	Error message not blocked
10	1024	Faulty warning lights on barrier	Warning lights has no fault
11	2048	Faulty warning lights on barrier blocked	Faulty warning lights on barrier not blocked

3.5. Alarm philosophy

The road traffic central in Bergen supervises approximately 270 tunnels. The tolerance for false or unnecessary alarms is extremely low. As an example: 'Alarm' for a stopped vehicle should not occur until the stop lasts for 15 seconds. If the stop is shorter, it can be neglected. This reduces the number of false/unnecessary alarms drastically. If a system gives one false alarm pr km pr day, it is worthless. We have been able to reduce it to between one and two pr km pr week in some tunnels. The goal is to reduce more. Several tunnels will give far too many alarms, especially in congestion areas or during wintertime when snow is dropped from vehicles.

As an example, The Arnanipa tunnel, 2km long, has less than one false alarm a week for stopped vehicle. During commissioning we do not accept false alarms on a closed tunnel. This tunnel is two-way traffic, approximately 12000 vehicles a day. But during winter the number of false alarms increase drastic.

False alarms from fire extinguisher removed are not tolerated at all. It is treated by the tunnel as confirmed fire and closing, and fire ventilation starts by automatic response. The operator must then think and open, not think and close. To avoid false alarms, for this it is important that strict demands for quality are part of the tender and confirmed during commissioning.

Where we often discover major errors are when we trigger a fuse in the technical buildings. We accept a maximum of 3 alarms for one fuse. If the main circuit breaker in a technical building is triggered, we accept the following alarms.

- Main circuit breaker triggered.
- UPS running in battery mode.

No other alarms accepted. All other must be filtered by the PLC.

If UPS power fails, only the alarm UPS power failure, and 1 communication error is acceptable.

The PLC and main switches should of course have double power supplies, one from UPS and one from normal power. If not, we will only have "communication failure".

When PLC fails it is only acceptable with communication failure.

For JET fans we sometimes have two alarms, if circuit breaker for control power fails, which is on UPS we will have the alarm for control power to the jet fan, and communication error to the soft starter/motor starter. These alarms must be filtered away if the UPS power has failed.

For communication failures the system defines "short time loss of connection" which is a maintenance alarm given if communication is down for more than one to three seconds. If the communication is gone for more than 30 seconds, it is changed to "communication error" and is given to the operator. This protects the operators from unnecessary alarms.

When power to an emergency phone is gone, do you really want an alarm for "handset not in position", or is "phone error" to maintenance enough. Remember that when the tunnel is equipped with AID, you already have an alarm for stopped vehicle, and a camera located on the area on screen if it is a real situation.

Time before an error or alarm is reported to Scada is a critical definition. An operator will normally use 90 seconds from alarm to activating response. If operator load is high, this time will increase. Does the operator need to know if a technical error exists for 20 seconds? Or is that just noise? EN62682 give that one operator should not have more than 6 alarms pr hour as the normal workload. The road traffic central operates on more than 30 as average.

3.6. Site acceptance test (SAT)

If the SAT is planned and performed by the contractor, the test will confirm what he has delivered, not what you ordered. That is why it is often performed User Acceptance Test (UAT) after the SAT. In Norway UAT is a short test, and confirmation of stability. SAT is planned and performed by the tunnel owner, or a representant for tunnel owner, and not by the contractor.

During commissioning we start by entering the technical building. Here take out circuit breaker for circuit breaker. This will show us if the network is according to plan, since it is designed with several small subnets. If circuit breaker Q12 takes out power to cabinet AS01, 03 and 05 I should lose communication only to these cabinets. If I have any other errors design plans are not followed. We cannot accept errors on anything under these cabinets.

This often gives us a communication error to the phone, the camera, and the fire extinguisher supervised by the cabinets that lost communication. If the road central receives all these alarms, then the cause of the alarms will be drowned by the secondary alarms. They will on SCADA see what is affected, and the alarm list will show the cause of the problem.

The reason we start with this is that this is where we nearly always find major errors. And quite often, things do not start up again as they should after power is returned.

During SAT we also monitor the log for communication to PLC's and RIO's and other critical equipment. If we discover unexpected loss of communication or other communication errors this is reported as major errors, that must be fixed before approval. We will also not accept that it takes more than 3 seconds before we receive the alarm for "loss of connection".

It has been discovered that some switches reboot too often, and thereby cause loss of connection. The only way to discover this is to analyze the system over time.

4. COMMISSIONING OF E39 SVEGATJØRN-RÅDAL

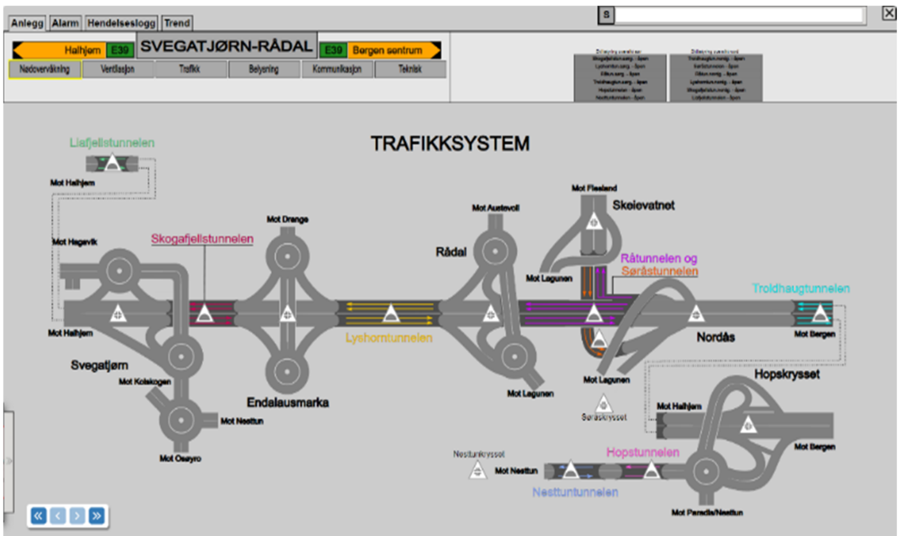

Figure 1: Overview of the project in Scada

The New tunnels is Skogafjelltunnelen 1500m. Lyshorntunnel 9300m, Råtunnel 2200 and Søråstunnel 2600m. Installations affected 7 junctions, which was also affected by 6 old tunnels. The "worst sign" had 20 different predefined pictures depending on which tunnels was closed.

All together it is approximately 5300 objects like camera, signs, communication control etc.

We did a thorough testing of traffic plans in simulator long before they finished installation. This way we could find minor errors in plans and software installation in an early stage.

All together it was more than 130 tables for traffic management, with large variations in size. They varied from approximately 10 cells to 20000 cells.

For each VMS sign for a given situation it was a cell containing the position the VMS should show. This can be adjusted from a web interface, and then downloaded to responsible PLC.

In simulations we could test traffic plans, illegal combinations of traffic plans, and closing of tunnels.

Table 2: Close Skogafjell tunnel northbound

Objekt SS_NL	Command sends to next level				
Kommando received from	SN_1	SN_2	SN_3	SS_SL	S_OS_Nord
AID	x	x	x		x
Lokal - Close	x	x	40		x
Lokal - Open	x	x	x		x
VTS - Close	x	x	40		x
VTS – Emergency close	x	x	x	x	x
VTS-Open	x	x	x		x
Fireplan – emergency close	x	x	x	x	x
High pollution -close	x	x	x		x
Emergency clos for southbound tube	x	x	x		x
X- send the message. If a number, wait n second before transmitting the message					

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Table 3: level 2 for closing tables.

Rutine SN_1	Command forwarded to			
Command come from	S_AS1001	S_AS1004	S_AS1005	TP_SN_1
SS_NL and SL_NL pone	1	1	1	off
SS_NL closed SS_SL open	2	2	2	activate
SS_NL open SL_NL closed	3	3	3	off
SL_NL, SS_NL closed	4	4	4	activate

ASxxxx are control cabinets for VMS and barriers. TP_SN_1 is a specialized lane signal plan for use when the tunnel is closed, to avoid "green arrows" visible from upstream the barriers

Table 4: Final level for closing tables, controlling the actual signs

Rutine S_AS1001	Object to position		
Command come from	VV10003	OG10003	
SN_1=1	101	101	
SN_1 =2	2	2	
SN_1 =3	3	2	
SN_1 =4	2	2	

In Table 2 we list the differ ways a tunnel might be closing. The next level can then be one of the columns. SN1 is a level two, and is an area with different control cabinet (ASxxx) who is controlling different VMS(VV) and barriers (YV) and yellow light (OG). This table might have an input from different tunnels. In SN1 we see that it is two tunnels that activates the area. One of the control cabinets are AS_1001. Routine AS_1001 will than put the sign to different positions depending of input. Position 101, is release control to other traffic plans, which enables us to set at lane signal plan, when the tunnel is closed, at ensue that it goes directly to this position when the tunnel opens for traffic. If now other plan is active 101 gives position 1.

It is all together nearly 140 tables of varying size for the project. The largest are for use of lanes signals and contained approximately 20 000 cells. All combination tested thoroughly on simulator. All together 14 different commands for close a tunnel in one direction affect the overall system. The "worst" VMS has 20 predefined positions. In addition, we had some illegal combinations of the use of lane signals and closing of tunnels, causing automatically closing of the next tunnel.

For all traffic control tables, it is a WEB-configuration for the position we would like the sign to show. During test by simulator, we could see that signs changed position as expected. During SAT we discovered that perception of distances is not the same on drawings as in reality. Quick changes in WEB-interface, and new test, without needing to change software was implemented. The road traffic central do not look on a single VMS, unless an error is reported. They never change position on a single sign manually. But maintenance can do this from Scada, when needed for maintenance purpose.

During SAT we closed tunnels and combinations of tunnels to confirm that all tables worked as intended.

For testing of traffic plans, we first confirm that status of VMS and lane signals to SCADA is correct. When we trust on the positions shown in SCADA, we don't need people in the field during test of the major traffic plans.

4.1. Factory Acceptance Test (FAT)

For the project E39 Svegatjørn-Rådal with 585 control cabinets the first FAT was performed with an empty control cabinet. Here the material experts used an x-ray gun to control steel quality. The contract demanded ANSI 316 for all parts. But for the first FAT hinges, screws and nuts were made of ANSI304. This was not approved, and we could point to numbered demands in the contract that not was satisfied.

We were able to find good solutions for excess fiber coil storage, improve design of installation of cabinets in wall elements. These problems were identified on the prototype of an empty control cabinet. Imagine the cost if this was discovered after production of 585 cabinets, already installed on site.

FAT of VMS signs and lane signals. Here it is of major importance to work together with the PLC supplier and the software engineers. Especially since we ordered them with a Modbus TCP/IP interface. With nearly 700 lane signals in one contract, we asked for three signals to be delivered to PLC supplier early. They could then test their software and the communication to the signals early. In the beginning it didn't work. After replacing firmware in the lane signals more than once, it worked in the laboratory. For the large VMS signs, we brought the PLC supplier to the factory. When Modbus communication didn't work, we left the software engineers from the two companies alone and tested other things. When we got back, they had solved the problems.

4.2. Test of Traffic objects

For each type of object to Scada a definition of data words to be sent to Scada exist. This is a good basis for a test plan for all objects.

After we tested status to Scada for all positions for all signs, we return to 10% of the control cabinets (60 cabinets) to an extended test. Starting with taking the power to the control cabinet. Did we have only expected communication errors? Very often you will discover unexpected alarms and reactions in the system.

Then we start to test with deliberate errors to see that consequence of the error we introduced is as expected. This is time consuming testing, but very important for stability in use of the tunnel.

4.3. Main problems during SAT

All together it was registered 1270 deviations from how thing should work during SAT of automation and safety systems.

Disturbance from late finishing asphalt work is common during SAT, and just something you have to expect.

During SAT we has a major focus on unnecessary/false /alarms error messages to Scada.

One thing we often discover, is that during normal operation of VMS and barriers it is an error messages lasting for 1 to 5 seconds during normal operation. For example, a barrier used 11 second to close, when it was expected to use 10 seconds, an alarm for undefined position is reported. This is not acceptable. Deley before error message increased to 30 seconds. Problem solved.

A major problem in many projects, including this, is alarm for grounding error. Suppliers should be informed about this early in the project.

It was several emergency phones standing error when they reported ready for SAT. Difficult to demand best emergency phones in open tenders. EEC regulations, when followed, makes it difficult to evaluate quality in a tender.

A very common error is, when a control cabinet has more than one VMS, and you are in the control cabinet and put one VMS status in "local", alle the others signs switch to "local" as well. This is never acceptable.

In several signs the graphic shown in Scada was wrong. The reason is an unsatisfactory communication with company implementing Scada.

Profibus DP communication to motor starters for JET-fans was not done right, so when we took the circuit breaker for control power to one motor starter, we lost communication to all. One minor circuit breaker caused a section of JET fans to be unavailable. When we discovered this in the first two technical buildings, we stopped testing until it was reported fixed.

5. SUMMARY AND CONCLUSION

All design must be done considering verification. Truth tables for all traffic signs must be made during design, and not by contractor.

For one project we are involved in, we are writing detailed tests plans for EET as part of the tender. We believe this will reduce the problems. Extra costs can be reduced by detailed descriptions for the software, where it is possible to refer to all functional demands and hardware demands, as demand number x y z. And that the supplier must sign that each functional demand is fulfilled and verified during EET.

It must be a demand that is exist no critical errors, and strict demands for number of minor errors. Short time errors defined to be shown to traffic operators are not tolerated at all. For each project it should be decided in the tender number of stable traffic errors that can be tolerated. Large project with 20000 signals will always have some errors, so "0 errors" are not realistic. For small two-way traffic tunnel (2km), zero errors should be possible.

6. REFERECES

(1) Norwegian Public Road administration, tender number 2016/132787 with associated drawings and papers
(2) SAT report: 616039-RIEAut-RAP-010-SAT, Multiconsult ASA for Norwegian Public Road administration
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