Commissioning Operation Control Systems

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ABSTRACT: A maglev line evidently needs an operation control system (OCS), but why should we use an auxiliary operation control system just for installation and commissioning? We present the basic concept of an commissioning operation control system (COCS) and discuss its benefits. From general and functional requirements, we derive a COCS function catalogue. We discuss risk analysis and safety targets. Modular design results in a ranking of COCS functions. It is recommended to keep COCS as simple as possible, and independent of OCS.

1 INTRODUCTION

1.1 Operation Control Systems

An operation control system (OCS) is the part of an overall maglev system that integrates all subsystems like operation control center, guideway elements, stations, maintenance areas, propulsion and power supply, and vehicles. An OCS contains all components and functions to control and monitor the safe maglev operation. In the following, we will refer to maglev systems of the Transrapid type, but the concepts proposed in this paper may also be applied to other maglev technologies, or to other highly automated, communication-based train control systems.

OCS allows to control the train movements and guideway elements both manually and automatically. On the base level, OCS provides all the safety functions generally known in railway signalling, e.g. train locating, guideway switch control, route protection (interlocking), and automatic train control including speed profile monitoring. There are some crucial differences between OCS and most existing railway signalling systems: First, all train control and train detection (train locating) functions are purely communication-based, using a highly available 38 GHz radio system (Schlichting & Müller 2005). Second, both motor and service brake are installed in the guideway, not in the vehicles (Henning, Hoke & Nothhaft 2004). Only the safe vehicle brake - used by OCS for emergency braking if the service brake has failed - is on board of the vehicle. Third, there are some innovative safety functions like “minimum speed profile monitoring” which guarantees the reachability of designated stopping points in the event of power shut-offs, transmission failures or hardware faults.

The following properties are shared by OCS and other communication-based train control systems:

- An OCS consists of wayside and mobile (onboard) components. Wayside components are either central (belonging to the operation control center OCC) or decentral, i.e. associated with individual guideway elements like guideway switches or propulsion substations.
- In any subsystem of OCS, three layers can be distinguished: “generic products” like general-purpose vital computer systems; “generic applications” like the Transrapid vehicle safety computer VSC (to be used for a class of vehicles); and the unique “specific application” designed for an individual line section or vehicle.
- A large fraction of OCS functions is safety-relevant and has to fulfill very high safety requirements. OCS is subject to the detailed and costly safety regime of the standards EN 50128 and EN 50129 (CENELEC 2001, 2002) including comprehensive and time-consuming verification, validation, assessment and acceptance activities. A description of the safety assessment and approval process of the Shanghai maglev line is given by Wu (Wu 2004).
- The safety activities, too, can be structured by the categories generic product / generic application / specific application. For instance, if an existing line is extended, the safety approvals of generic products and generic applications might be reused, but the new specific application has to go through verification, validation, and assessment.

- Some tests can be carried out in test centers, but others have to be performed on site with real vehicles on real guideway.

1.2 Commissioning Operation Control Systems

A maglev line evidently needs an operation control system, but why should we use an additional operation control system just for the installation and commissioning period? In terms of the standard EN 50126 (CENELEC 1999), we are referring to the life cycle phases “installation”, “system validation (including safety acceptance and commissioning)”, “system acceptance”, and eventually “modification and retrofit”. In conventional railway signalling, there will be special rules and regulations for installation and commissioning, so usually it is not necessary to have special safety equipment just for these phases.

Maglev systems of Transrapid type, however, will profit from using an auxiliary “commissioning operation control system” (COCS). Table 1 shows the life cycle phases which belong to the installation and commissioning period, and the corresponding activities which involve maglev train operation.

Table 1: The installation and commissioning period - its life cycle phases and activities.

EN 50126	Phase	Typical activities involving maglev train operation
Phase 8	Installation	Subsystem tests Installation tests System integration tests
Phase 9	System validation	Validation tests Safety acceptance tests Safety qualification tests Operability tests Training Demonstration runs VIP runs
Phase 10	System acceptance	Acceptance tests Trial operation
Phase 13	Modification	Installation tests Safety acceptance tests

During the activities listed in Table 1, OCS has neither been fully validated, assessed, nor approved. Thus OCS cannot take full responsibility for safety. The conventional railway approch would be to implement a complex structure of restrictions, intermediate steps, precautions and procedures. There are, however, some maglev-specific reasons for using a COCS instead:

- Transrapid emergency braking involves a wayside propulsion shut-off, i.e. it is not an autonomous function of the maglev vehicle. Therefore, there must be a safe command link from the vehicle via the operation control center to the power substation.
- The very high speed of Transrapid vehicles results in long braking distances which cannot be handled by driving manually “on sight”. A comparatively small difference in velocity makes a large difference in braking distance and stopping point.
- Because of the fully automated operation under OCS, there are no wayside colour-light signals which could be observed by the test driver.
- Because of the shape of most Transrapid guideway types, it is not feasible to install visual marks or signs for location or velocity information which could be read at any speed and under all weather or lighting conditions. Visual marks indicating permitted speed can be valid for a few standard missions (routes and stopping points) only.
- In the future, there might be maglev vehicles with very restricted visibility to the guideway in front.
- Unlike a conventional railway system, the overall maglev system consists of tightly interlinked and interdependent components. Without COCS, most of the subsystems and their components would have to be tested, validated, accepted and approved in a strictly sequential order. With COCS, some of these activities may run in parallel, saving valuable project time.
- Because of the novelty of the overall maglev system, the approval process is likely to contain safety qualification tests lasting several months. On one hand, this trial operation should be as close to the normal revenue operation as possible. On the other hand, OCS cannot take full responsibility for safety. This dilemma is best solved by a COCS.
- The novelty of the maglev system leads to frequent VIP and demonstration runs before OCS is finally approved, like the VIP run in Shanghai on December 31, 2002.

1.3 Basic COCS Concept

A COCS could be implemented in different ways, for instance within OCS by combining approved OCS modules with special COCS modules. Such an approach has obvious limitations and drawbacks. The basic COCS concept proposed here is a so-called “safety bag”. According to EN 50128 (CENELEC 2001), “a safety bag is an external monitor, implemented on an independent computer to a different specification. This safety bag is solely concerned with ensuring the main computer performs safe, not necessarily correct, actions.”

2 GENERAL REQUIREMENTS

2.1 Independence

OCS and its “safety bag” COCS must work in parallel and independently. The safety reactions of COCS should not cause any side-effects and errors of OCS functions. It must be possible to install and test innovative concepts and OCS versions which do not yet have safety certificates.

2.2 Fault-Tolerance

COCS must be fault-tolerant against failures of the communication systems. For instance, short interruptions of the train-to-wayside radio should not result in severe safety reactions of COCS. If necessary, this fault tolerance must be bought at the price of maximum velocity. The main objective of this requirement is to avoid unnecessary interruptions of tests and demonstration runs. A secondary objective is to prevent that frequent COCS reactions disguise the presence of OCS faults and thus delay their detection and removal.

2.3 Capacity and Performance

It must be possible to select vehicles for COCS supervision, and to deselect non-operative ones. A vehicle equipped with COCS must be able to run on regular service maglev sections no longer equipped with COCS. It must be possible to run several trains simultaneously on the new maglev line. COCS must support all defined route destinations and speed profiles. It is not sufficient to support only a few standard missions (e.g. end-to-end shuttles). If possible, the safety reactions of COCS should be of graded severity.

3 FUNCTIONAL REQUIREMENTS

3.1 Basic Functions for Train Operation

For the basic functions of an automated train control system, we refer to the “urban guided transport management and command/control systems” standard IEC 62290-1 (IEC 2006). It covers all “grades of automation”, including driverless operation (GOA3) and unattended operation (GOA4), and all “grades of line” including high-speed lines, although its scope is urban transport only. Table 2 lists the basic functions for GOA 3 and 4 as far as applicable to a maglev system.

Not all of the functions listed in Table 2 are mandatory for all train control systems, and not all have to be implemented by a maglev OCS. It is the task of the “risk analysis” phase (CENELEC 1999) to identify operational hazards and evaluate risks, so that functional safety requirements and safety targets can be derived. Some functional requirements will be affected by local conditions, e.g. the presence or absence of platform screen doors, or might be fulfilled implicitly. For instance, the combination of platform screen doors and an elevated guideway will prevent collisions with persons on tracks. The functions from Table 2 that are required by the risk analysis of a specific application will be implemented in the specific OCS, or will at least interface with it.

Table 2: Basic functions for driverless or unattended train operation according to IEC 62290-1.

Basic function	Subfunction
Ensure safe movement of trains	
	Ensure safe route
	Ensure safe separation of trains
	Ensure safe speed
	Authorize train movement
Drive train	
	Control acceleration and braking
Supervise guideway	
	Prevent collision with obstacles
	Prevent collision with persons on tracks
Supervise passenger transfer	
	Control passenger doors
	Prevent injuries betw. platform and train
	Ensure safe starting conditions
Operate a train	
	Set in / set off operation
	Change driving modes
	Operate train betw. two operational stops
	Change the driving direction
	Supervise the status of the train
Ensure detection & management of emergency situations	
	Detect emergency situation
	Handle emergency situation

3.2 Guidelines for COCS Functionality

From the basic train control functions introduced above, we have to select those which are to be covered by COCS. We may distinguish between mandatory and optional COCS functions. In any case we shall bear in mind that COCS is used for test and demonstration runs only - not for regular revenue service. For instance, we may look at the functional scope of the first such system, the “auxiliary OCS” (AOCS) used for the commissioning of the Shanghai line (Wu 2004). AOCS provided a multi-path emergency stop function so that immediate forced stops could be initiated by staff in the OCC, the maintenance area, all power substations, and all vehicles. Thus AOCS was designed to “handle emergency situations”, including eventual OCS failures and eventual collisions with obstacles on the tracks.

We propose the following guidelines for selecting COCS functions. First, COCS must cover test and demonstration runs only, not the regular revenue service. Second, even under COCS supervision, all required train operation functions have to be controlled completely and comprehensively by OCS. In compliance with the safety bag concept, COCS shall not actively contribute to any OCS functionality. Third, we have to be prepared for the fact that the generic or specific OCS application is not yet approved, and that it might contain residual, potentially hazardous errors.

3.3 Catalogue for Selecting COCS Functions

With the above guidelines in mind, we can reduce the functions presented in Table 2 to a generic subset from which the COCS functions for a specific application can be selected. This catalogue is shown in Table 3. Note that it still contains both mandatory and optional candidates for COCS.

Table 3: Catalogue for selecting COCS functions.

Basic function	Subfunction
Ensure safe movement of trains	
	Ensure safe route
	Ensure safe separation of trains
	Ensure safe speed
	Authorize train movement
Ensure detection & management of emergency situations	
	Handle emergency situation

All functions have been eliminated from Table 3 that are not safety-relevant, or whose failure is handled by another function remaining in Table 3. Also, all functions have been removed that are usually covered by organizational means under commissioning conditions.

For instance, during the installation and commissioning period, there must be a strict regime of rules and regulations concerning the admittance of staff, construction workers, test crews and demonstration run passengers to platforms, vehicles and tracks. Demonstration runs have to be staffed adequately to prevent all hazards related to passenger transfer, e.g. guiding passengers on the platforms and locking passenger doors mechanically.

4 COCS FUNCTIONS

4.1 Provide Emergency Stop

Emergency situations, including eventual OCS failures and eventual collisions with obstacles on the tracks, cannot be handled reliably and quickly by voice communication only. It is a mandatory COCS function to provide a safe emergency stop. As mentioned before, the Shanghai AOCS provided a multipath emergency stop function which could be initiated by staff in the OCC, all vehicles, and other locations. Possible reasons for initiating an emergency stop might be an emergency request from other staff, or an operational irregularity, e.g. a wrong train movement, a wrong route, or an overspeed condition.

As regards Transrapid technology, the COCS emergency stop will be implemented as an “immediate forced stop” involving a wayside propulsion shut-off and a full activation of the safe vehicle brake, i.e. the on-board eddy-current brake.

If possible, the safety reactions of COCS should be of graded severity, allowing to choose between an immediate forced stop of one particular vehicle and an immediate forced stop of the whole fleet.

4.2 Authorize Train Movement

It is a basic function of OCS that trains cannot move without specific driving instructions. During the installation and commissioning period, the train operation manager in the OCC must additionally authorize any vehicle movement on the maglev line. Usually, this movement authorization will be issued verbally over radio to the test driver, before the OCS drive instruction is transmitted.

To reduce the error-prone voice communication, it is recommended to authorize train movement formally via COCS. This function requires the train operation manager to enter vehicle number, starting point and destination point into COCS. Where more than one route exists between these points, it is also necessary to select the desired route. COCS will transmit and display the information to the train driver. COCS movement authorization can be used as a stand-alone function, but it is also a technical prerequisite for the functions “ensure safe speed”, “ensure safe separation of trains”, and “ensure safe route”.

4.3 Ensure Safe Speed

Speed profile monitoring is a basic OCS function. During the installation and commissioning period, the test driver must additionally supervise safe speed. The decision whether speed is safe or not depends on the actual route, the actual location, the actual velocity, topographical data, and braking curves. As explained in section 1.2, this is a demanding task for the test driver, and it is difficult to install auxiliary wayside marks or signs for location or permissible speed information.

It is therefore recommended to have COCS monitor the maximum speed profile. Technical prerequisites are the movement authorization function (see 4.2) and a vehicle locating function. In case of overspeed, COCS will automatically initiate an emergency stop.

4.4 Ensure Safe Separation of Trains

Again, this is a basic OCS function which cannot take full responsibility for safety during the installation and commissioning period. It is recommended to relieve the train operation manager in the OCC from keeping track of all vehicles by having an equivalent COCS function. Technical prerequisites are a vehicle locating function and the movement authorization function (see 4.2). COCS will check that the route is clear of other vehicles before issuing the movement authorization to the train.

4.5 Ensure Safe Route

This is the basic OCS interlocking function dealing with route reservations for trains, locking and monitoring all movable guideway elements (e.g. switches), route monitoring and route release. During the installation and commissioning period, special organizational and technical measures have to be taken for proving the correct position of the guideway switches and for additionally locking the switches in the correct position prior to movement authorization.

This entails the employment of special switch guards. The time-consuming locking and unlocking procedure and the verbal communication with the train operation manager make it difficult, if not impossible, to perform realistic trial operations and stress tests with several trains. Therefore, this functional complex is a candidate for COCS, too. Technical prerequisites are a vehicle locating function (which is needed for route release), switch position detection, switch locking, and the movement authorization function (see 4.2). COCS will additionally lock the guideway switches and check their correct position before issuing a movement authorization.

5 RISK ANALYSIS AND SAFETY TARGETS

5.1 General Structure

A COCS is definitely not intended for commercial passenger service, but it must be safe enough for all test, VIP, and demonstration runs. This is to say, it must reduce the residual risk of OCS to an acceptable level. Risk analysis and safety targets are needed for two purposes: First, to decide which safety functions should be included in the COCS for a given specific application. Second, to choose a COCS architecture and design which is appropriate for the required level of risk reduction.

In principle, safety targets can be of a quantitative or qualitative nature. Quantitative, stochastic targets are suitable for designing and rating safety measures against random faults of hardware components or transmission channels. Qualitative targets are suitable for choosing adequate organizational and procedural measures against systematic errors. The latter can manifest themselves in system concept, specification, architecture, design, and construction - for instance in software coding, application data generation or hardware wiring.

5.2 Quantitative Safety Targets

EN 50126 and 50129 show some ways to derive quantitative safety targets - usually “tolerable hazard rates” for top-level functions - from statistical data. One approach is to start with the statistically achieved risk of an existing, equivalent transport system and to require that the new transport system should be at least as safe as the existing one. So the global target for the new transport system is set. Then, the global target is broken down from the overall transport system via its subsystems (guideway, propulsion, vehicles, OCS, etc.) to each of the top-level functions of the subsystem in question (like “ensure safe speed” of OCS or COCS). This so-called “apportionment” of global risk portions to subsystems and then to subsystem functions is very arbitrary and open to attack. Another problem is the fuzzy statistical relation between the tolerable hazard rate of a particular top-level system function (including hardware, software, and handling failures) and the calculated failure rate of the equipment implementing this function (including hardware failures only, but having stochastic effects on other system functions, too).

We propose a different approach avoiding the break-down and the arbitrary apportionment. Basically, we compare the individual risk R_C of a reference user class (e.g. the passengers of high-speed railways) with the individual risk R_S induced by the technical failure of the subsystem in question (e.g. COCS). R_C and R_S might be represented by fatalities per passenger hour, casualties per passenger km, or similar quantities. R_S takes the user profile into account, i.e. R_S is a function of the frequency and duration of exposure to the induced hazard. Assuming that the risks R_C and R_S are compatible in dimension and denotation, we can calculate the “safety distance”

$$d = 10 \lg (R_C / R_S) \quad [\mathrm{dB}] \qquad (1)$$

The safety distance d can be estimated on a preliminary basis during the system design phase. The final calculation of the safety distance will be part of the safety case. In any case, the safety distance is used as a safety indicator or benchmark. This leaves room for comparison with the state of the art and for continuous improvement, whereas a top-down apportionment is likely to produce arbitrary results.

The first step is to identify the COCS user classes and their reference user classes, in order to define the individual risk R_C and the user profile for calculating R_S. For COCS, the most relevant user classes are tests crews accompanying test runs, and passengers attending demonstration or VIP runs.

Test crews: The reference user class consists of railway staff. R_C can be taken from accident statistics; a typical value is 2×10^{-8} fatalities per work hour. The user profile of the test crews is characterized by frequent test runs, long exposure time, and very small passenger numbers.

Demonstration run passengers: The reference user class consists of passengers of high-speed railways. The user profile of demonstration run passengers is characterized by infrequent runs (less frequent than test or revenue runs), short exposure time, and large passenger numbers. The safety targets for both user classes must be handled separately.

5.3 *Qualitative Safety Targets*

It is a generally accepted rule of technology that at present, the integrity of a system against systematic errors is not quantifiable. The relevant standards have adopted the notion of a "Safety Integrity Level" (SIL). The SIL is a discrete safety index ranging from 0 (no safety requirements) to 4 (very high safety requirements). For each level, the standards list adequate combinations of organizational structures, design principles, verification and validation methods, languages and tools, etc.

For COCS, we derive the qualitative safety target by applying the risk graph method described in IEC 61508 part 5 (IEC 1998). Considering the user profiles of both test and demonstration runs, and assuming a "slight probability" of hazardous OCS failures, the risk graph yields SILs of 3 and 4. For all practical purposes, we take SIL 4 as a basis. Note that it is not justified to translate this index into quantitative targets.

6 ARCHITECTURE AND DESIGN

6.1 *General Considerations*

The design of COCS should implement the above safety targets in conformity with the railway standards EN 50126, 50129 and 50128.

COCS will consist of wayside and on-board equipment. For some COCS functions, there are options how to allocate the function to the central, decentral and mobile parts. For instance, speed profile monitoring could be implemented fully on-board or partly on-board, partly wayside.

COCS might even be divided into subsystems for speed profile monitoring, route protection, etc. For each subsystem, an appropriate safety architecture (e.g. 2-out-of-2, 2-out-of-3, 1-channel reactive fail-safe) might be derived from the safety targets.

COCS should use no safety-relevant OCS functions, so that all parts of OCS may be updated freely. Rather, COCS should be a *diverse* system, avoiding common concepts and parts with OCS. Exceptions can be made where COCS uses interfaces between OCS and other systems like propulsion, or where COCS uses transmission channels which are also used by OCS. Of course, the "safety case" has to demonstrate the functional independence between OCS and COCS. For instance, if OCS and COCS are using a common transmission network, COCS should treat the network as an open channel, taking adequate measures against any hazardous influence from OCS, other participants, or the network itself.

6.2 *Support Modules*

The top-level COCS functions presented in Chapter 4 have to be based on a set of support modules such as vehicle locating, track occupancy modelling, switch interlocking, and communication.

Vehicle locating: This is an on-board function best implemented by using a satellite navigation system (GPS, GNSS / Galileo) for obtaining location, direction of travel and velocity data. The GPS equipment should be selected carefully to cope with reduced satellite reception and multi-path reception. Vehicle locating must function correctly inside station buildings and tunnels, so it will be necessary to use an additional on-board position sensor, e.g. a long stator slot counter as used for propulsion control. Also, two diverse satellite navigation systems should be used per vehicle, to meet the safety targets more easily, and to cope with systematic errors. An important software topic is sensor fusion, i.e the blending of the diverse sensor channels.

Track occupancy modelling: Based on vehicle locating, this function keeps a record of all vehicles, whether running, stopping, or stabled. Any track section or route must keep the status "occupied" in the event of locating or transmission failures.

Switch interlocking: This function reads the end position of guideway switches and locks the switch electrically if it is reserved for a COCS route. The interfaces between OCS, COCS and switch control should be carefully designed to avoid a deadlock in case OCS throws a switch locked by COCS.

Communication: Emergency stop commands, movement authorizations, location data, switch indications and commands, and watchdog signals have to be transmitted between the distributed parts of

COCS. As with Shanghai AOCS, cryptographic methods have to be applied to ensure integrity and authenticity.

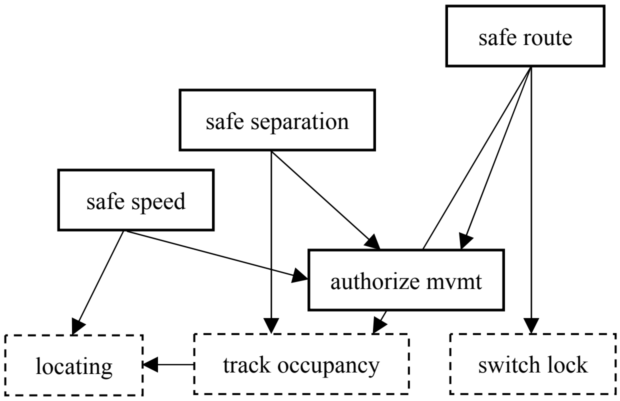

Figure 1: Modular design of the top-level functions and their support functions. The emergency stop function is not shown.

From Figure 1, we can derive a ranking of the top-level COCS functions in terms of increasing hardware and software support:

1. Provide emergency stop
2. Authorize train movement
3. Ensure safe speed
4. Ensure safe separation of trains
5. Ensure safe route

6.3 *Simplicity of Function and Design*

To limit the expenditure of time and equipment, and to maximize safety, we recommend to keep the functional requirements and the architecture of COCS as simple as possible. Obviously, if COCS is not extremely simple, then a vicious circle will be entered, since COCS is a safety-relevant system in itself and thus needs validation, assessment and and approval.

One possible approach is to allocate only simple input / output functions to the decentral and mobile parts of COCS, i.e. those located in propulsion substations, switch boxes and vehicles. Speed profile monitoring, on the other hand, is more fault-tolerant and precise if implemented on-board, as opposed to a wayside implementation.

Another helpful approach is to start with a very simple COCS for the early test phases. Gradually, the scope of functions and the performance can be extended to meet the demands of safety qualification tests and full trial operation.

Fault-tree analysis shows that the safety targets can be more easily fulfilled if there are no failures of COCS which are hazardous by themselves, in absence of OCS failures. In other words, the interface between OCS, COCS and the other maglev subsystems must be such that COCS can only issue commands that are at least as restrictive as the original OCS commands. COCS must, even in case of own failures, never be able to remove restrictions (e.g. braking or delevitation commands) imposed by OCS.

It should also be checked if inexpensive industrial PLCs (programmable logic controllers) can be used for the decentral and on-board parts of COCS.

7 CONCLUSIONS

7.1 *Summary*

While it is indisputable that a COCS will improve the efficiency and safety during the commissioning of high-speed maglev lines, there is a broad scope of possible candidates for COCS functions. We consider the emergency stop function as mandatory, the other functions - movement authorization, safe speed, safe separation of trains, safe route - as desirable. It is important to keep COCS as simple as possible, otherwise there will be no gain in the approval process. COCS should neither be overloaded with “nice-to-have” functions, nor with the complexity of OCS.

7.2 *Open Problems*

Further development of risk analysis and safety target calculation is needed. Safety targets should help in selecting COCS functions for a specific application, and in making decisions on details.

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