Megatrend urbanization

The numbers are self-explanatory. In 1800, only three percent of the world’s population lived in cities. 2007 was a milestone in human history: for the first time ever, more people on earth lived and worked in cities than in rural areas. The UN estimates that the proportion of city-dwellers will climb to 61 percent by 2030, pushing up urban population from three billion today to a total of five billion.

And only a few of the twenty biggest megacities with populations over 10 million will be in industrial nations; the others will be in threshold and developing countries. By 2015, some 350 million people will live in these megacities. As a consequence, accelerating urbanization and economic growth will fuel a massive demand for adequate infrastructures such as energy and water supplies, and transportation.

At the same time, the cities’ economic attractiveness will continue to grow. Even today, cities such as Dhaka, Cairo, Seoul, Buenos Aires, Mexico City and Tokyo already generate between 40 and 60 percent of their respective country’s gross domestic product (GDP).

Findings of a stakeholder research project

Siemens has recently supported a research project conducted by GlobeScan and MRC McLean Hazel into megacity challenges [1]. The methodology of the research was based on a stakeholder survey covering 25 cities and metropolitan areas with, on average, approximately 20 interviews for each city and area. The cities and metropolitan areas chosen where defined as “megacities” in accordance with the definition of the United Nations and were selected on the basis of being the most populous cities in the world.

The respondents came from four stakeholder groups: elected politicians, employees of the municipality, private-sector infrastructure providers and people in a position to influence infrastructure decision-makers.

According to the stakeholders in urban development and transport, the continuous and sustainable growth of city regions and economies constitutes a major challenge for the infrastructure, demanding efficient transport management and planning.

These sprawling conurbations are creating new urban dynamic forces. Commuters frequently travel large distances from densely populated suburbs or other cities nearby.

Sustainable urban development calls for a high level of efficiency of the existing infrastructure for a holistic approach to the challenges at a metro-regional level.

These demands require a transportation system that can be operated independently in the inner city area and integrated into a rail network serving the wider metropolitan area.
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Table 1: List of megacities [2] surveyed in this research project.

Meanwhile, many railway operators worldwide are already moving from a national standard to an international standard that will allow unrestricted cross-border traffic. The leading standard for national railways is the ERTMS/ETCS standard. Most existing rail networks have been in service for decades and many national train operators are concerned to revitalize the existing infrastructure.

With a high-quality infrastructure in place, the challenge has shifted toward coping with the need to renew aging systems or dealing with obsolescence where the installed infrastructure no longer meets operational requirements or changing service expectations.

**Maximum flexibility in the urban transport network**

The transport needs in booming conurbations are continuously growing. People are constantly on the move, whether on their way to work, traveling to leisure or educational facilities or while shopping or returning home. Efficient mass transit systems are therefore key to achieving maximum mobility in cities and large urban areas worldwide, promoting urban and regional economic development.

Efficient mass transit systems that can be easily adapted or upgraded to the increasing transport capacities are required for maximum mobility. The public transportation systems in inner cities and urban areas must support the growing demand for convenient and time-efficient urban and suburban services.

The performance of mass transit systems is largely dependent on the performance of the automatic train control (ATC) system deployed. With increasing automation, the responsibility for operations management is passing from the driver and operator to the system.
An ATC system incorporates functions for the monitoring, operation and control of the entire operational process. It can feature different degrees of automation such as manual train operation with a driver, semi-automated train operation and driverless operation. An ATC system displays the current driving instructions on the cab console and supervises the permissible train speed continuously. Color-light signals can thus be dispensed with in the higher levels of automation. The functional scope of ATC systems is focusing more and more on cost reduction.

The most important qualities demanded by train operators are:

- safety
- performance
- cost-effectiveness
- maintainability
- upgradability
- scalability

The ATC system should be designed on the basis of the latest technologies available and comply with international standards. Only if this approach is integrated into the system development, can it be guaranteed that the ATC system will be future-proof and support the operators, municipalities and governments in fulfilling their obligation to provide an attractive transportation system for day-to-day riders.

Technologies to meet modern rail transport requirements

The state-of-the-art technology of communication-based train control (CBTC) systems meets the operational requirements for safety, performance, quality and reliability for high- and medium-capacity metro systems. However, the CBTC systems of the various system providers are mostly unique in their system architecture and have been designed neither for mutual operational compatibility nor for compatibility with national railway networks.

In some areas, it is economically or environmentally necessary to employ mixed operation, for instance where metro systems serving the inner city and suburban railways serving the greater metropolitan area share the same tracks.

Metro operators and national railway operators prefer a unified operational concept and demand maximum operational safety. Operation on such lines should be at least under ATP supervision and should prevent accidents caused by human failure in the case of manual train operation.

There are currently no independent standards defining functional requirements for interoperability with ERTMS/ETCS standards to be satisfied by a CBTC system. Standardization will enhance performance, availability, operations and train protection, and permit new CBTC applications.

Both the CBTC system and ETCS system need to have fixed and switchable balises for train locating and track-to-train communication. Balises are passive transponders powered by the passing trains. When a train goes over one, it transmits a safety-relevant telegram to the on-board subsystem, which identifies the balise and allows its position to be determined in the rail network with the aid of the on-board track database. Switchable balises transmit a safety-relevant balise telegram, which also contains the movement authority, to the train's on-board subsystem, which reads the balise information and reacts to it.

Communication between the wayside balises and the on-board balise subsystem is via the air gap in accordance with the data package specifications from UNISIG.

In this paper a detailed technical proposal is presented for the standardization of CBTC systems based on the ERTMS/ETCS standard. The proposal focuses on the ETCS Level 1 standard.
Interoperability principles

Consensus-driven approaches take a long time to reach a common specification. In the case of the standardization of ERTMS/ETCS in Europe it was approx. 10 years before the first common version was agreed. Even now, work on it continues, with all the major countries concerned having their own test and pilot projects and introduction strategies.

As one of the world leading suppliers of signaling systems with our more than 100 years’ signaling experience, Siemens is active in all major working groups such as the European MODURBAN group, the international IEC T9 working group 40, UNISIG etc. for the standardization of mass transit systems.

According to IEC 62290-1:2006 [3], "interoperability refers to the ability of a transport network to operate trains and infrastructures to provide, accept and use services so exchanged without any substantial change in functionality or performance. This ability rests on all the regulatory, technical and operational conditions which must be met in order to satisfy all the defined requirements applicable to the given grade of automation taking into account grade of line, irrespective of which supplier provides which components or systems."

The interoperability subsystem characteristics can be evaluated by reference to a common international standard or other relevant documents, independently of the system in which the constituents are to be integrated.

Interoperability subsystems can be designed and developed individually. The easiest point at which to implement interoperability is the train-to-wayside air-gap interface.

Air-gap links between the wayside and on-board equipment can be by means of continuous or intermittent communication channels.

Hence the most useful ATC system is one that can provide open standardized interfaces at the balise interface and radio link interface.

Trainguard MT, with its modular system architecture, is the ATC product developed by Siemens to the latest standards to meet both present-day and future interoperability needs.

Continuous train control using CBTC systems

For the most efficient operation, the ATC system concept must be based on the moving-block headway principle implemented by a cyclical exchange of position report telegrams sent from the trains to the wayside subsystem and of movement authority telegrams from the wayside subsystem to the trains.

The wayside subsystem calculates the movement authority on the basis of interlocking statuses and train position reports. The on-board subsystem supervises train operation within the dedicated movement authority limits.

The wayside and on-board subsystems use a track database (TDB) containing the track topography description. The TDB consists of linear segments each with a certain length, adjacent segments and descriptions of additional information such as speed and gradient profiles. Thus, if the TDB is available on board, there is no need to transmit all this information via the communication channel. This enables the necessary bandwidth of the radio communication system (RCS) to be reduced.

The on-board subsystem supervises and controls train movements based on its train locating function, the information received from the wayside subsystem and information stored in the TDB.

The operation of the ATC system described is designed according to the principles laid down in the current standards.

Provided the trains and wayside have the appropriate equipment, the system can be operated at level of automation 3 (GoA3) or 4 (GoA4) as per IEC 62290-1:2006.
Intermittent train control (ITC)

Intermittent train control operation is based on the fixed-block principle. The headways are ensured by the interlocking using conventional route monitoring (clear signal aspect when all the necessary conditions are met permitting a train to enter the section in advance of the signal).

A lineside electronic unit (LEU) is connected to the signal to select the switchable data balise telegram information in accordance with the signal aspect. If the signal clears, the switchable balise sends a movement authority telegram to the on-board subsystem while the train is passing the balise.

The on-board subsystem uses a TDB as described for continuous ATC. Based on the TDB information and movement authority received, the on-board subsystem supervises and controls the train's movements in accordance with the train's location.

Intermittent ATC is used as a simple interface to, as well as an overlay system for, existing signaling systems. If required by the railway operator, existing interlockings and signals can be used in refurbishment projects to avoid operational disturbances.

The architecture of the intermittent train control system can be extended for continuous ATC at a later stage.

Figure 1: ATC system architecture for continuous train control (CTC) operation.
In intermittent ATC, as well as continuous ATC, the system relies on the interlocking functionality for safe route management (e.g. route locking, route setting, route release) even if all the trains are operated at CTC level. Interlocking overrides, allowing a different signal aspect (or cancelation of a signal aspect) to be displayed to CTC trains, are sent from the wayside subsystem to the interlocking, for instance.

For maximum flexibility, it may be necessary to have the ATC system operating at different train control levels and in multiple train operating modes. The levels and modes depend on both the equipment of the territory where the train is currently running and the equipment available on board the trains.

Provided the trains and wayside have the appropriate equipment, the system can be operated from GoA0 to GoA2 in accordance with IEC 62290-1:2006.

**System interfaces for train-to-wayside communication**

The ATC system is embedded in its environment with its own logical interfaces and components. For mass transit applications two communication methods can be distinguished.
Continuous ATC in accordance with CBTC standards
For data transmission, the ATC system uses the data communication system (DCS). This communication channel allows bidirectional communication between the wayside subsystem and on-board subsystem. The DCS acts as a transparent data channel between the two subsystems. The ATC system has a logical interface to the DCS to support the RCS function. The on-board subsystem provides the DCS with information about the train's position. Although the DCS will work without it, this information can improve the DCS's availability.

Intermittent ATC in accordance with ETCS/ERTMS standards
For the train-to-wayside intermittent communication, the ATC system uses Eurobalises at the wayside as well as a balise antenna and balise reader on board the train as specified for ETCS level 1 (UNISIG Class 1 System Requirement Specification 2.2.2). This standardized Eurobalise communication channel allows unidirectional data transmission from the wayside subsystem to the on-board subsystem via all balises.

The balise telegrams for the ATC system are specific to the mass transit application and conform to the ETCS balise interface specification. They are embedded in ETCS packet 44 (“data used by applications outside the ERTMS/ETCS system”).

The information provided to the on-board system by switchable-data balises comprises:
- balise ID
- balise version
- movement authority

Safe train separation at ITC level
A safe interval between trains and ATP at the ITC level depend on fixed blocks that are interlocking routes delimited by signals whose aspects are controlled by the interlocking. The routes generally correspond to a stretch of track between two signals.

The underlying interlocking in the ITC displays a proceed aspect only if the entire route up to the next signal and an optional overlap are determined to be clear by the track vacancy detection system.

The switchable balise connected to the LEU sends the ITC movement authority (ITC_MA) derived from the signal aspect. In Trainguard MT (TGMT), deterministic and non-deterministic movement authorities can be distinguished.

An ITC_MA is valid from the position of the main signal balise up to the point of protection (POP) relative to the next main signal (e.g. track vacancy detection section boundary).

Deterministic ITC_MA
The deterministic ITC_MA is used if the next main signal can be derived unambiguously from the signal aspect.

A deterministic ITC_MA defines one vital and one non-vital movement authority limit (MAL) and extends up to fixed target points (end of track, signal etc).

The non-vital MAL defines the location at which the train is required stop operationally.
The non-vital MAL is configured some distance in rear of the next main signal balise. In case the infill balise does not provide an ITC_MA corresponding to "signal shows proceed aspect" or no infill balise is present, the train is brought to a stand in front of the main signal balise.

A deterministic ITC_MA is delivered with TGMT packet 2. This balise telegram provides vital and non-vital MALs and the positions of all facing points within the ITC_MA path.

If the signal does not show a proceed aspect, the on-board subsystem will get an ITC_MA with zero length, causing it to trigger emergency braking.

Note: The handling of ITC_MAs is the same as for CTC_MAs.

**Non-deterministic ITC_MA**

The non-deterministic ITC_MA is used if the next main signal cannot be derived unambiguously from the signal aspect due to unknown point positions in the ITC_MA path.

Hence, the non-deterministic ITC_MA specifies only the "known" part of the path to the destination and the maximum path length to the possible (expected) repositioning balises.

For ATP speed supervision, the on-board subsystem determines the most restrictive speed profile and the worst-case grade of all possible paths up to the possible repositioning balises.

The on-board subsystem monitors the detection of a repositioning balise up to the maximum path length to the possible repositioning balises. If no repositioning balise is detected within this maximum path length, the train location status becomes "delocalized".

**ITC_MA received from repositioning balise**

When the train passes over a repositioning balise, TGMT packet 4 is received and the non-deterministic ITC_MA extended as a deterministic one.
Figure 4: Example of a non-deterministic ITC_MA at signal S1.

Initial situation:
- Signal S1 shows a clear aspect because it has received information about the locked route. A route is set from S1 to S21.
- Signal S1 can determine whether track 3 or track 1/2 is locked but is unable to distinguish between track 1 and 2.
- In the situation described, the route is set to track 1.

Balise A contains the following information:
- TGMT packet 1
- TGMT packet 3, which contains the point status "left" of P1, point status "unknown" of P2 and distance to the farthest repositioning balise.

Balise B1 contains the following information:
- TGMT packet 1
- TGMT packet 4, which contains the valid ITC_MAL (position of the protecting points assigned to S21).

Sequence of steps in the example:
1. The on-board subsystem receives a non-deterministic ITC_MA from balise A.
2. The on-board subsystem determines the lowest grades and speed restrictions for the alternative paths via track 1 and track 2.
3. The on-board subsystem expects either balise B1 or B2 as a repositioning balise.
4. The on-board subsystem receives the repositioning information from balise B1. From then on, the on-board subsystem supervises a deterministic ITC_MA from S1 to S21.

ITC_MA received from infill balise
The ITC_MA received from an infill balise merely extends the existing ITC_MA. The ITC_MA of the infill balise is only valid in advance of the associated main signal balise. The area between the infill balise and associated main signal balise is not covered by the ITC_MA of the infill balise.

Thus, infill balises can only be used to extend ITC_MAs already received, not to perform a level transition to CTC.
Infill balises extend existing ITC_MAs any distance in rear of the main signal balise. In order to ensure that the ITC_MA extension by the infill balise is still valid at the location of the associated main signal balise, however, the on-board subsystem must check the validity of the ITC_MA extended by the infill balise and that the balise information of the main signal balise is read.

Provided the trains and wayside have the appropriate equipment, the system can be operated at level of automation 2 (GoA2) as per IEC 62290-1:2006.

**Validity of an ITC_MA extended by an infill balise**

An infill balise extends an existing ITC_MA based on the next activated route ahead. As a cancelation of the next route cannot be excluded, however, the ITC_MA received by the infill balise is not valid for an unlimited period of time. The ITC_MA received by the infill balise is discarded if its currency expires or the train comes to a stand between the infill balise and next main signal balise. In case of a discarded ITC_MA, the on-board subsystem supervises the previous ITC_MA up to the main signal ahead.

**Supervision of the main signal balise at ITC level**

At ITC level, the on-board subsystem supervises the detection of a main signal balise. If an expected main signal balise is not read, the on-board subsystem initiates emergency braking and performs a transition to the next lower level of automation (manual train operation using the interlocking).

The reading of a main signal balise is always supervised at ITC level, independently of the reception of an infill ITC_MA.

**Operational versatility**

Operational versatility is one of the essential benefits of such a state-of-the-art ATC system. A wide variety of situations exist where differently equipped vehicles, various communication methods and multiple operating modes can coexist on the same line, requiring the operators to be extremely flexible in their operation of the system.

The following key characteristics demonstrate the benefits of such an ATC system:

**Mixed traffic**

The term "mixed traffic" is applied to the operation of trains equipped with the ATC system automatically and simultaneously with unequipped trains (no on-board equipment, e.g. engineering trains, or incompatible on-board equipment) in the same territory.

Thus, the range of each train is extended and different trains can be controlled in a mixed traffic environment, be they mainline, suburban or freight trains. Thus, the infrastructure can be utilized in a highly efficient manner.

Unequipped or incompatibly equipped trains to be operated on the main line can run on the lines using the traditional wayside signals and equipment. By following the indicated signaling and rules for on-sight running, the driver can still operate the train safely on the basis of clear information.
**Mixed operation**
Vehicles equipped for continuous communication to ensure short headways in moving-block operation on inner-city lines can change over seamlessly to intermittent communication on suburban lines equipped accordingly.

Switching from continuous to intermittent communication takes place automatically. This can also increase system availability during migration phases or when upgrading an existing train fleet or signaling system.

**Performance**
Thanks to the versatility of the ATC system described, it is possible to have moving-block and fixed-block functionalities in a single system. As the system supports both train control levels, it can provide greater flexibility for railway operators to meet their respective transportation needs and hence offers far more than a normal CBTC system.

**Modularity and scalability**
The ATC system is a scalable system with an innovative modular design. Its software and hardware components incorporate the latest standards and interoperable interfaces to ensure compatibility with existing subsystems.

The modular design also ensures that up-to-date hardware and software innovations can be implemented smoothly when updates or improvements are required.

**Upgradability**
The ATC system can be upgraded from fixed block to moving block. This enables headways to be reduced to meet present and future requirements.

Moreover, both the level of automation and the performance can be upgraded. A performance upgrade depends on the chosen method of communication. The level of automation can be upgraded from manual through semi-automated to driverless train operation.

A line equipped with this ATC system can easily be extended to include more stations and trains. The upgradability of the ATC system ensures optimum investment protection.

**Reduced operation and fall-back mode**
The ATC system is designed with various redundancy and fall-back levels so that, in the event of a partial failure, operation can continue without any loss of performance or degrading.

Radio failures and brief losses of communication have no effect on safe train operation. The movement authority and train position are valid as the location is calculated independently of the communication channel.

**Interchangeability**
The ATC system offers open and standardized interfaces for train-to-wayside communication. This unique advantage will allow operators of the system to standardize their system requirements, which will in turn enable manufacturers to offer interchangeable system solutions.

**Expandability**
Once in operation, the ATC system will also meet the future requirements for network growth and help reduce operational investment.
The author

C. Schmelzer; Senior Sales and Project Manager for train control systems at Siemens AG, Sector Industry, Division Mobility, Rail Automation, Mass Transit, Brunswick, Germany

After joining Siemens Transportation Systems in 1996, he worked in project management for mainline and mass transit projects in the fields of overall system design, rail automation and electrification. Since 2003 he has been employed as a senior sales manager for automatic train control systems and been involved in market research and future product strategies.

References