Railway Coordinates: State of the Art and a Tremendous ongoing Potential

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Key words: Track work, Railway Coordinates, “Coordinate based, process driven, topology structured data management”, towards maximum quality of all the railway data.

SUMMARY

The structuring power of coordinates has changed the railway track work radically. The start of the change coincides with the introduction of a new, absolute coordinate based track machine guidance method at Swiss railway (**SBB)** in 1986. Ten years later the new working method was in operational use for the entire railway network. It generated both economic and organisational advantages.

This new net-wide errorless track data sets the route for more than two dozen track machines operating each night on the SBB track net.

This coordinate approach also implies a large potential for improving the global railway data quality.

The major key word for this change is “Coordinate based, process driven, topology structured data management”.

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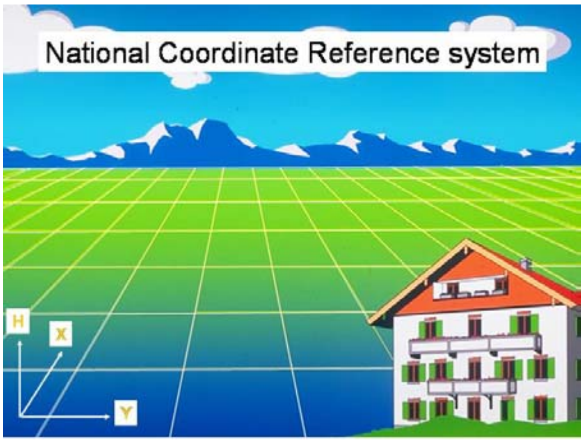


Fig. 1. Coordinate based object referencing

Fig. 2. Reference point for the track survey

1 OVERVIEW

The aim of this text is to present the thread between the 80's with classical coordinate use for establishing the railway map and the new "coordinate based, process driven, topology structured data management" initially developed to support the track data domain and extendable in the future to the global field of railway data.

This development opens an important potential to improve the railway management, based in the future on fully CORRECT, COMPLETE and operationally USABLE data on railway facilities.

The **components** are the facilities of the railway infrastructure determined in the national coordinate system (Fig. 1, Fig. 2) exclusively managed through consistency checked actions driven from the maintenance process for data changes. This approach generated benefits as described in chapter 2.

The relationship between **track net data** used as subset of reference data and other types of coordinate data use is presented in chapter 3.

The **approach** of a stepwise introduction of the "coordinate based, process driven, topology structured data management" is described at chapter 4.

Chapter 5 draws **ongoing potential** emerging, once the data quality is obtained by putting the work process idea into practice.

Chapter 6 presents the issues of **in-depth studies.** Despite the evident geodetic nature of the subjects, their railway practice oriented character prevails.

2 DEVELOPMENT IN THE TRACK DOMAIN

2.1 Start

Traditionally coordinates are used for representing the railway infrastructure facilities on the railway map. Today GIS based informatics is used to support this work.

In 1986 the track experts of the Swiss railway started extending this traditional usage of track coordinates.

In close cooperation with the Swiss track industry and with the support of railway survey, the guidance of track machines on the basis of coordinate referenced points and coordinated track geometries was developed.

Elements from geodesy, mathematics, physics, and business-administration contributed to the stepwise establishment of the solution. At the end 90s it was operational with a net-wide complete and errorless track data fundament.

2.2 Before

Perfect track geometries were rare when using traditional, relative track positioning methods. This was the case until the 80s. These methods allowed a reasonably correct setting out of the form of the track geometry. Considerably more difficult was their correct positioning in space. The track constructors were neither able to easily detect nor to correct orientation mistakes. If a track machine operated towards a fixed point, rough edges were repeatedly built in the track alignment. Fig. 3 shows the example of a slight orientation mistake at the beginning of a circle element. This curve progressively drifts away from its correct track position. Arriving at the following metal bridge, the track must be forced back exactly to the position of the theoretical track alignment.

2.3 Oscillation Step-up

The rough edges initiated an oscillating step-up movement of the trains. At each train passage, the swing pattern was accentuated and finally it transmitted itself to the track as a long wave deformation. The track position started drifting more and more away from the ideal track position. Deforming dynamic forces, impacting the track, became bigger and bigger. The track deformation increased and so did the track maintenance costs.

2.4 Improvement

The described error source of long wave track deformation was largely eliminated when use of absolute coordinate track data at highest quality level was started. It allowed to measure and to calculate track geometries, reference points and constraint points in the same coordinate system. For the first time in the long history of railways, it was possible for the first time to define, construct, and maintain globally optimised track alignments. With certified and stable geodetic reference points as basement, the track geometry after each track machine work always corresponded to the theoretical best alignment.

2.5 Methodology

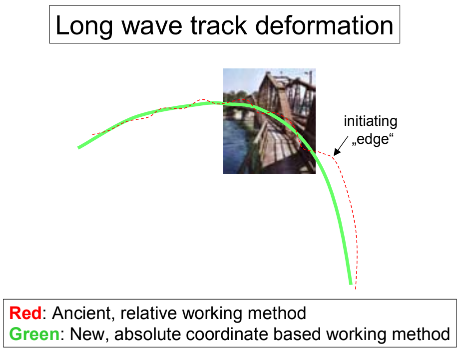
When implementing the method, the track machine starts by calculating its position through spatial vectors measured to the reference points. This allows determining the lateral shift by referring the calculated position to the theoretical track alignment. The tamping machine uses this shift value for precise laying of the track to its theoretical alignment position.

2.6 Components

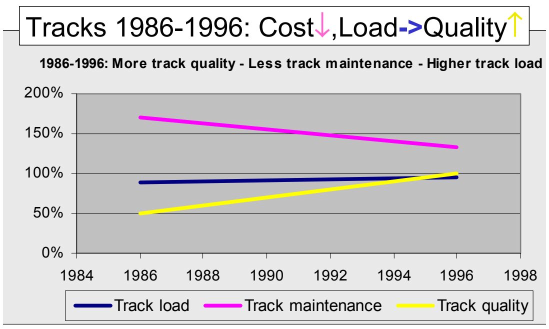
To achieve the described results, the following tasks from different disciplines had to be solved:

- **Geodesy** with the aim to guarantee for all the track work a unique reference in an absolute coordinate system. To guarantee this on cm-precision level, a mm-precise coordinate reference was needed.
- **Mathematics** with the aim to calculate best possible track geometries[1].
- **Physics** with the aim to optimise the dynamics of the train movement. The velocity determines the length of the transition curves. The track geometry is generally a compromise allowing to run freight trains and intercity trains with varying velocities on the same track alignment.
- **Process control** with the aim to optimise the numerous work-steps needed until tracks are properly maintained and/or renewed.
- **Data management** with the aim to automate the work steps. All data changes will exclusively be operated from the work process with full IT based steering of the automated consistency checks. Human dependence in data-update always bears the risk of man made, uncontrolled data errors.

The assembly of these components into a single operative track management tool was the crucial step allowing the break through of the new way of work.



3. Absolute / relative (red) track geometry



4. Cost effectiveness of the new method

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[1] The shape of a mathematically defined track axis is a sequence of the track elements: straight line, circle element and transition curve. The start point of each track element is defined within the national coordinate system. The track net is made of track and switch segments. It's an optimisation result. This takes into account limitations (constraint point) of the clearance gauge. This for bridges, platforms, traction current installations, tunnels and so on. Finally many constructive limitations must be respected: e.g. isolation distances to signals, distances between parallel tracks.

2.7 Consequences

The progress achieved by the use of absolute track coordinates have a milestone character.

Positively, the following can be underlined:

- **Handling**: A very high acceptance of this global track management system by the stakeholders at all the track work levels.
- **Quality**: Between 1986, when the new method first was used, and the end of the change, ten years later, the portion of main tracks with highest quality doubled from 20% to 40% net-wide (Fig. 4). Highest quality means a track score of 10 to 22 points measured by a measuring wagon on a scale ranging from 10 points for the best to 110 points for the worst track quality.
- **Exploitation**: In December 2004, SBB implemented its project Rail 2000. From one day to the next 14% additional train traffic was brought on the track network. The achieved track quality increase was one of the pillars assuring this success.
- **Organisation**: During the 10 years since the method became fully operational, no track machine breakdown due to erroneous numeric track data occurred. Over the SBB track net, each night about two dozen track machines use coordinate based data for high precision track positioning. Something like a hot line would never have worked to support this work in critical situations. The only way was setting and reaching the 100% data-quality and -completeness target.
- **Strategy**: The major part of the track work consists at least in the final stage, of the dressing of the track geometry with absolute coordinates. This means that with the new working method, most of the track work passes through the use of absolute coordinates.
- **Economy**: The increase of the track quality during 80's – 90's allowed to constantly reduce the annual track maintenance and renewal budget, representing half of the global amount, spent for all the types of the infrastructure facilities.
- **International**: A supra national consolidation step was accomplished with the introduction of the UIC leaflet 728R [UIC1] and, since 2003, the working method in use on the French high speed net, illustrates some outcomes of the working method at international level.

Still to be clarified are the following subjects:

- **Stability**: In the future systematic (process driven) coordinate control of the reference points must be guaranteed. They must be accompanied, in case of detected movements, by correction measures of the coordinates. Today this control isn't yet systematically operated [TE1].
- **Best practice**: Because most of the track machinery operating today doesn't dispose of an absolute coordinates steering device, the method can't be used at a large European scale.

- **Global approach**: The awareness, that the data quality increase is only possible when the three factors “coordinates”, “process” and “topology” interact, is still very low, even amongst track and data specialists.
- **Double work**: The measuring and management of geodetic reference points is not yet optimally tuned between railways and national surveys.
- **Education**: Today the use of railway coordinates isn’t systematically taught. Railway coordinate knowledge is mainly acquired on the job within the railway companies.
- **Complexity**: For many observers, coordinates as a sequence of numbers, give the impression of a specialised area of expertise. To step into this area is done only very carefully.

Globally: The described development covers to a great extent the needs for track construction and track maintenance of SBB. From the European point of view further consolidation phases are still necessary.

3 THE DOMAINS OF COORDINATE USE

At railways coordinates are today used in different only loosely interconnected contexts. The potential of optimal linkage of the different domains is unexploited. This chapter roughly describes the fields of action and drafts the exchangeability potential. The advantages of independence of the fields of action shall remain, but the reference data domain is to be strengthened.

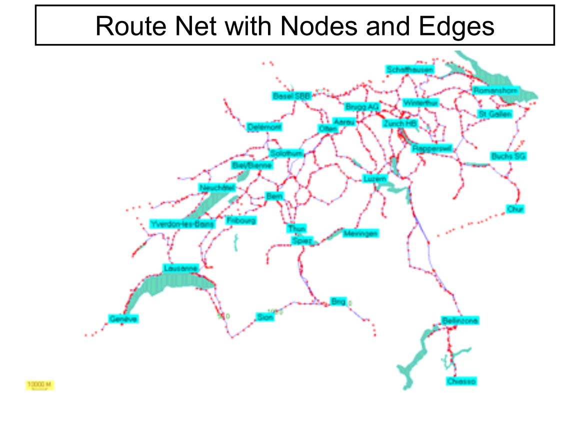
3.1 Basic reference data

They serve for referencing all the other railway data. They are composed by route data[2] (Fig. 5) and based on them the work surfaces (Fig. 6) needed to support interdisciplinary data exploitation of heterogeneous data quality.

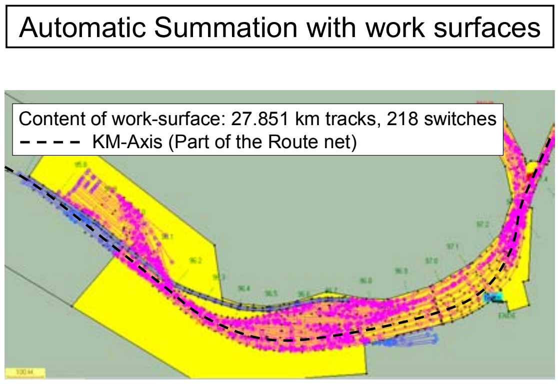
The track data, per se clearly technical data as described hereafter, can also be considered as basic reference data, because for many specialised services the reference to the track data makes more sense than the reference to the route net.

Data used for referencing must be complete and errorless.

[2] The topologic structure of the route net is constructed as following: First the coordinates of the nodes are defined. A node is a point in the centre of a railway station or a stopping place. Historically, plug gauge were fixed on the train forwarding buildings. Some of them today still exist physically. In the jargon of railway data a node is called „station traffic point”. On the nodes the route net is constructed by putting edges between the nodes which model the traffic lines between stations. The edges are coordinate based, geometric route alignments. With this way of construction it is guaranteed that the nodes and the edges are complete and correct. A node can only be changed when all the route alignments (the edges) ending at that node are previously cleared, newly calculated and stored again by controlling all consistency conditions.



5. Route net of the Swiss Rail



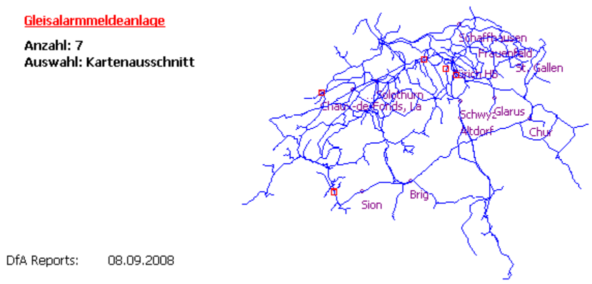
6. Work surface constructed on the route net

3.2 Technical Data

Thanks to the coordinates assigned to all data types of the specialised services, these can be represented numerically on lists (Fig. 7) and graphically on maps (Fig. 8), opening so the advantages of the GIS-approach at a broad railway data level.

Linie	Km	Km bis	Standort
100	50.642	51.142	Paluds, Les : St-Maurice Tunnel / Tunnel / Galleria
100	51.718	52.294	St-Maurice Gebäude / Bâtiment / Fabbricato
224	29.27	29.773	Chaux-de-Fonds, La Gleisfeld / Faisceaux de voies / Campi binar
650	31.844	32.35	Lenzburg Gleisfeld / Faisceaux de voies / Campi binari
660	18.258	19.345	Horgen Oberdorf : Sihlbrugg Tunnel / Tunnel / Galleria
660	18.258	19.345	Horgen Oberdorf : Sihlbrugg Tunnel / Tunnel / Galleria
711	20.095	21.632	Bonstetten-Wettswil : Hedingen Gleisfeld / Faisceaux de voies /

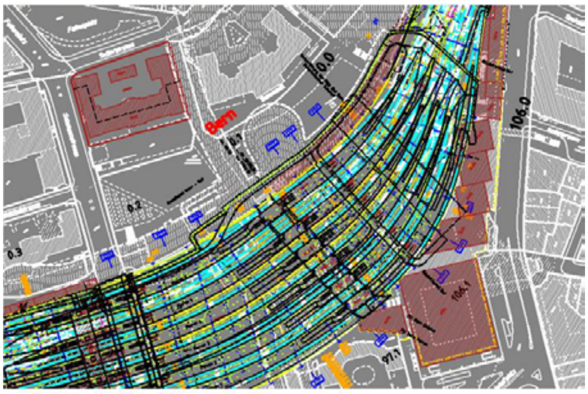
7. List representation of railway facilities.



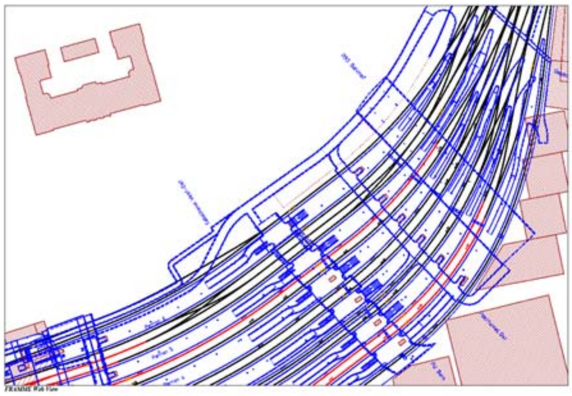
8. Graphic representation of railway facilities.

3.3 Railway map

The global graphic picture (Fig. 9) and a specific layer selected out of it (Fig. 10) are only two different ways for presenting the railway map content with modern GIS-based working methods.



9. Railway map: global view.



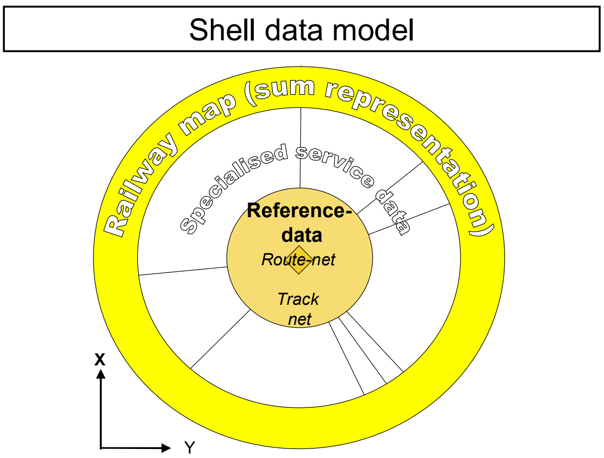
10. Railway map: platform and buildings.

3.4 Interaction

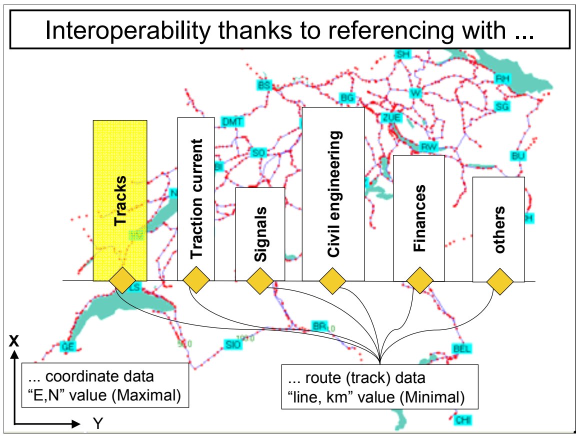
The relationship between the basic reference data, the track data und the various technical data from the specialised services is illustrated as a shell model (Fig. 11) with:

- The kernel – The basic reference data composed of the route data and the work surfaces. Its quality is complete and errorless.
- The first shell – The track data. Its quality is complete and errorless.
- The second shell – All data from the specialised services, with varying completeness and correctness.

Fig. 11 shows the functionality of the railway map. It is the sum of the inner data shells. Lower data quality and possibly missing and erroneous data is the weak point of the traditional railway map.



11. Shell data model



12. Minimal and maximal data interoperability

3.5 Consequences

In regard to Fig. 12 one can say that:

- The reference to the route data guarantees a minimal geographic interoperability between data types, if the KM-axis are primarily calculated in the national coordinate system.
- The reference to national coordinates is a pre-requisite for maximum interoperability of data at object detailing level, supposed that all the data are calculated in the same coordinate reference system.
- If railway data are referenced in the coordinate system, they will always fit together, even if the owners of the different data types ignore each other before the data are to be matched.

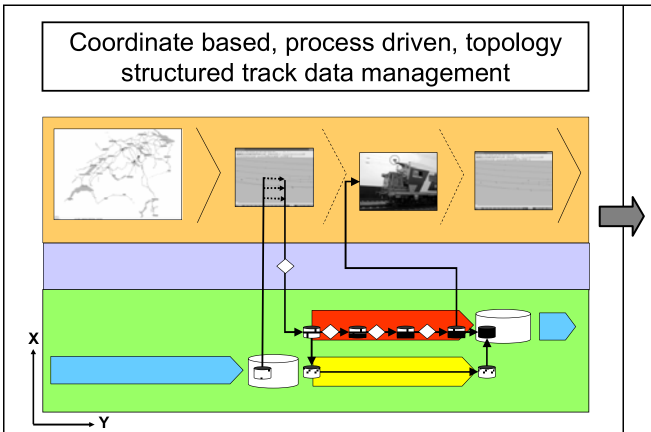
4. ONGOING DEVELOPMENT OF COORDINATE USE

Today track data is the only field where technical data based on coordinates are exploited at almost 100% completeness und correctness level. Nevertheless, the benefit would be similar for all other data domains of the infrastructure based on the "coordinate-process-topology" approach.

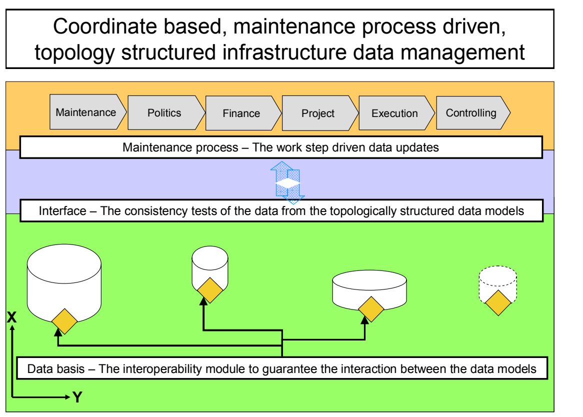
4.1 Process orientation

The way towards maximal data quality was opened through "coordinate based, process driven, topology structured data management" in the track work domain (Fig. 13). All data updates are controlled and activated by the steps of the track work process.

In a visionary view, one can replace the track work process by the general maintenance process (Fig. 14) and imagine all data updates occurring anywhere in the infrastructure being steered analogue to the track data domain. The result would be a "zero error" database content. Manual changes with their unavoidable "non zero" error rate are definitively made impossible.



13. From the track work process …



14. … to the Infrastructure Maintenance Process

4.2 Consequences

Unlike the track application, the global maintenance process addresses not only one but many databases, namely technical databases, financial databases and others.

The condition for a successful “coordinate based, process driven topology structured data management” is the interoperability, achieved through data referencing between all the databases being involved in the work process steps.

This requirement is fulfilled with two measures:

- The improvement of the interoperability of the data by relating them to the reference data.
- The review of the data storage, for which the topological structure must model the physical reality of the railway facilities correctly.

The consequences of ignoring this recommendation is, besides the error quota leading to a low data usage and a lack of efficient control tools, the increased risk of parallel data management.

- The data of the specialised services are not used for supporting the work process because of their effective or assumed low data quality;
- For management tasks – e.g. reporting – new datasets with assumed „high reliability“ because of being „self made“ are compiled;
- The resulting parallel needs for data care binds additional manpower for manual adjustments.

In contrary a consistent referencing and „coordinate based, process driven, topology structured data management“ guarantee:

- Support of the deployment of standardised mechanisms to store, archive, authenticate access, transfer, preserve, curate, certify and interpret railway data;
- Increase of availability of primary sources of data in digital form;
- Shift of the balance away from approaches based on secondary sources being often incomplete and incorrect;
- Use of data as the central element of the professional facility management.

5 OPENING POTENTIAL

The following clauses illustrate the potential of high quality data in new usage domains. Common to all of them is their reference to coordinate approaches and/or to the field of geodetic science.

5.1 Train control

There exists a potential for improvement in the signalling and train control-command area. In the context of conventional signalling, the engineering of outdoor equipmentsuch as line-side signals and track vacancy proving devices can be rationalised. In the context of the new European Traffic Management System ERTMS, it may become possible to replace the trackside devices for odometric calibration, the so called Eurobalises, by other geodetic positioning means. Studies of the International Union of Railways (UIC) have shown that this “virtual balise” concept is feasible with an adequate Safety Integration Level, provided that the trains have access to a map of the route on which they are running, meaning that trains run on the basis of coordinate based track data.

5.2 Increase the transport capacity net-wide

A potential for optimising time tables, based on the geodetic approach of the “least square network compensation” concept, will possibly contribute to raising the transport capacity of the existing track net.

Starting with known track data as “way component” and given train velocities, the “network compensation” optimises the best time component using the basic equation “Velocity = Way/Time”. The “network compensation”, through its statistical sensitivity analysis, allows examining the consequence of the traffic interruption of a single route on the global net. By means of differentiated weighting of the single routes, strategies for minimising the effect of breakdown on the global net or on parts of it can be derived.

On this basis it is (at least theoretically) imaginable to envisage the building of an extended time table concept, allowing raising the train density on the existing track net. This can be achieved by making the straightforward increase of the train succession on the lines between the nodes, fully manageable in the crossings of the railway stations.

5.3 Road

Basically the topic of managing road data is the same as for the railway and can therefore be transferred to it in large parts. The contrary – from the road to the railway – is unrealistic, because of the higher precision needed in the railway domain.

5.4 Consequences

The coordinate potential is very broad and reaches far beyond the aspect of data quality. Its full benefits need to be explored in dialog with the concerned specialists. Only such an approach will allow establishing the basist for achieving the development steps drafted in this chapter.

6 SUBJECTS FOR FURTHER STUDY

From the previous chapters in this text the following subjects for further study are formulated:

From chapter 2 on **track data**:

1. The elaboration of an easy to handle global **stability** check approach of the reference points.

From chapter 3 on **data interoperability**:

2. The question of **immutability** of construction data values after having transformed them because of map projection. On a map representing crossings, the deviation radius (e.g. 185m) isn’t allowed to change after transforming data because of map projection. This must be guaranteed even if a decimal place writing would be generated mathematically (e.g. 185.1473).

3. The choice of the best suitable projection system. How must track and crossing data be **stored** to guarantee a best possible link between the stored data and there graphic representation on a railway map? Is it possible to define a transfer standard?
4. Formulation of the best practice to harmonise the reference of railway facilities on the basis of coordinates and that used classically at railways with line-km values without coordinates.

From chapter 4 on **data management**:

5. Formulate a step-wise **build up** of "coordinate based, process driven topology structured data management" between technical and financial data, increasing the data quality and the data interoperability.
6. Development of **work surfaces** allowing the adjustment of data from various origin and quality.
7. Formulate the best practice for the build up and maintenance of the **reference data** needed by all the data-bases involved in the maintenance process tasks for data update operations.

From chapter 5 on **enlarged coordinate use**:

8. Define a continuous representation approach of tracks for border crossing train control use. If different map projection systems do not fit together, a continuous track representation is impossible. The solution at European level passes through the use of the ETRS89[3] coordinate reference.

7 ONGOING

Railway in general and tracks in particular are the same in each railway company. It therefore makes sense to plan the further development of absolute coordinates themes in a cross border, interdisciplinary teamwork approach.

Given the success of the geodetic services of the national surveys in harmonising the coordinate reference systems at European level by referring to the ETRS89 system, it will be of major benefit to involve the national survey representatives in the project team with the following objectives:

1. **To discuss and decide on the geodetic themes outlined in this text to enhance the interoperability of all the technical and financial data of the railway infrastructure.**

[3] According to the glossary of the UIC leaflet 728R [UIC1] the ETRS89, European Terrestrial Reference System 1989, is described as following: Reference system defined by the sub-commission EUREF of the International Association for Geodesy (IAG) in 1989. The scale and fundamental point of ETRS are identical with the ITRS (International Terrestrial Reference System) and since that moment it follows the movement of the stable part of the Euro-Asiatic tectonic plate, allowing in a first approximation the determination of coordinates in Central and Northern Europe, invariable in time.

This shall be done by choosing a stepwise approach to „coordinate based, process driven, topology structured data management“.

2. **To define a railway practice based strategy for a stepwise replacement of the actual railway coordinates systems by ETRS89 compatible coordinate references.**

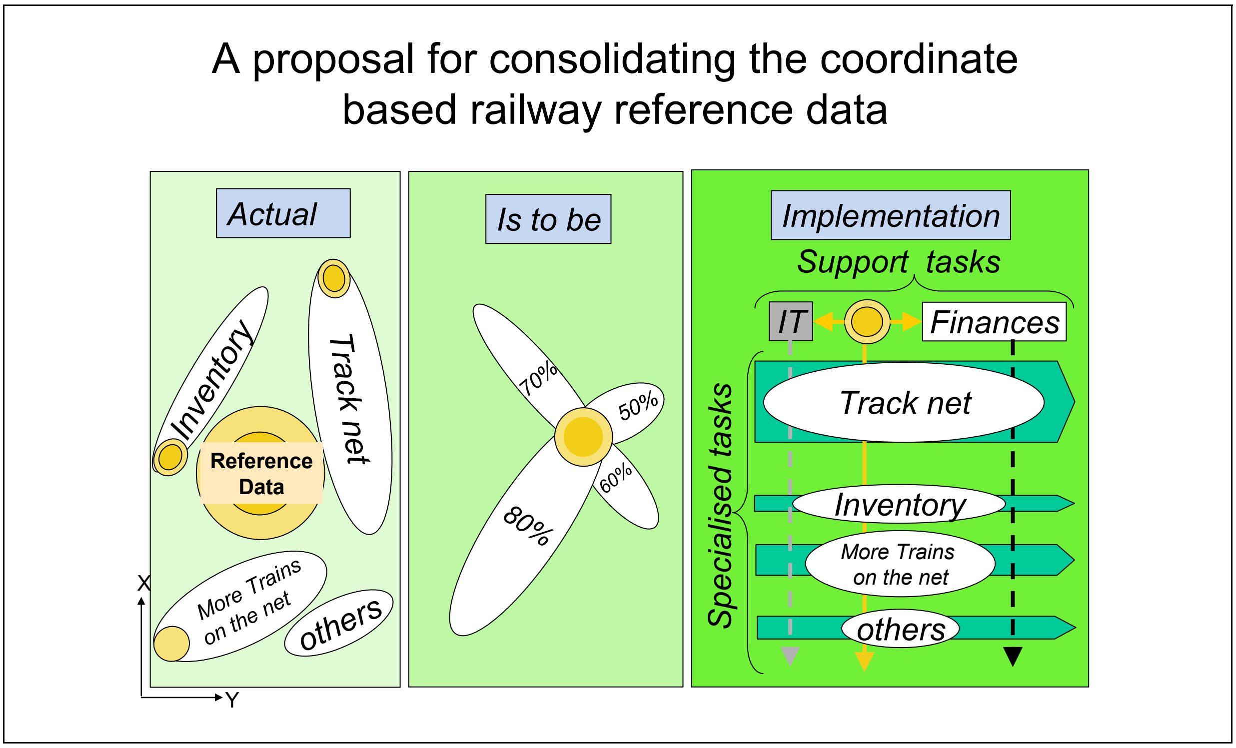
   This shall prepare the trans-national use of track data, for supporting the future of train control at European level.

8 CONCLUSIONS

The importance of coordinate data radically changed due to the development in the track machine steering domain since the 80's. From the marginal use of representing the railway assets on the graphical railway maps, coordinates suddenly became the core element of the track work. Half of the global annual maintenance and renewal budget is spent in the track domain. Most of the track work is today coordinate based.

The potential of this approach for the global railway data management is evident. The "coordinate based, process driven, topology structured data management" plays a **key role in accelerating the development** (the title of the Working Week 2009). An enormous efficiency potential can be mobilised by extending this concept to the management of all financial and technical data. Another field of potential use will be opened through putting into practice, what today still appears as visions of extended coordinate usages: train control, increase of train capacity due to the use of coordinate working methods for optimising timetables, …

The following figure sets the point of conclusion of this texts thoughts. It offers an invitation to an interdisciplinary dialog whose next aim should be the operational implementation of the organisation suggested on this diagram.



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BIOGRAPHICAL NOTES

Théo ENGEL, Swiss, 57 years old

Education

Basic education as "Ingénieur du genie rural et géomètre" at polytechnic university Lausanne (ETHL). Then extra-occupational: Post diploma in Soil and rock mechanics (ETHL), Swiss Federal Licensed Surveyor, PhD in an interdisciplinary project on terrain and rock instabilities (ETHL), Certificate in business administration (SBB). German, French, English, Spanish speaking, with consolidation periods of varying length in the respective countries.

Professional activity

Practical professional experiences in all the domains of education. Employments in private engineering companies, administration and research. At Swiss railway (SBB) from 1985 onwards in various domains:
SBB regional office until 1999: Work within data management subjects. Collaboration on several projects in various roles: Initiator, participant, lead. Main outcome: Concept of the technical global assets database, development of a new, track work management system based on coordinates. Parallel to the development work, permanent involvement into the operative track renewal process with direct terrain contacts and connections to all the technical domains of the railway infrastructure (civil engineering, traction current, signalling and others).
SBB head office from 1999 onwards: Work in the strategic asset management. Initiation and lead of the traction current program management. Actually: lead of the inventory of the financial facility database with focus on the methodological support of supporting the specialised services in their inventory task. The task is supposed to end in interconnecting financial and technical data as the basement for management optimisation.

Further international tasks

Initiation and executive collaboration on two European projects on education within the COMMETT program in the 90's. From 2002 onwards: expert in several projects from UIC, particularly the lead of the redaction group of the UIC leaflet 728R on Railway geodesy, adopted in 2006. Since end 90's: Member of the redaction team of the reference book "Eisenbahnbau".

Some extra professional tasks

Secretary of the FIG 6 Commission (Engineering survey) 1986 – 1994 and Swiss national delegate in this commission. Building up and lead of the FIG 6.4 “Transportation and utility lines” working group from 1986 to 2002. Chief Financial Officer of the Swiss Alpine club (120’000 members) between 2003 and 2006. Avalanche specialist in the army.

Jürg KAUFMANN, Swiss, 66 years old
Nationality: Swiss
Education
– Federal Institute of Technology ETHZ, Dep. Mathematics/Physics, 1962,1963
– Federal Institute of Technology ETHZ, Dep. Rural Engineering and Surveying, Diploma 1967
– Diploma of Institut Mössinger, Business-School
– Licence as Swiss Federal Licensed Surveyor, 1981

Languages
German, English, French, Italian

Consulting Experience
– Member of the Project Management Board of 'Reform of the Swiss Official Cadastral Surveying'
– Consultant to national, cantonal and municipal authorities for Cadastre and GIS in Switzerland
– Consultant for Cadastre Projects in Belarus, Ukraine, Kosovo, Serbia, Macedonia, Azerbaijan
– Chief Technical Advisor for Georgia
– Consultant to the Government of the Principality of Liechtenstein for implementation of the National Geodata Infrastructure
– Member of the drafting committee for the Law on Geoinformation

Professional Experience
– Since 1988: Independant Consulting Engineer, KAUFMANN CONSULTING
– 1981-1988: Keller Vermessungen AG, Switzerland, Chief Executive Officer
– 1979-1981: Federal Institute of Technology Zürich, Senior Assistant Geodesy and Land Information Systems
– 1970-1979: Digital Ltd, Zürich, Informatics Services for Engineering, Director
– 1967-1970: Federal Institute of Technology, Zürich, Assistant Land Management and Cadastre

Main international and national mandates and awards
– Delegate of the Swiss professional organization of surveyors in FIG, Commission 7, Cadastre and Land Management
– Member of working group 'Statement on the Cadastre'
– Chairman of working group 'Cadastral reform and procedures; Cadastre 2014‘
– President of the Swiss Association of Geomatics and Land Management since 2005
– Honorary member of FIG since 2006

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