FME Rail
(no. 26538)
WP 3: Reference Case Studies & Classification
WP 4: Dissemination — FME Rail Address List and Railway Bibliography
IT/DTU Deliverables D.3.1–.5 and D4

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Abstract

This document constitutes the IT/DTU Work Package 3 and 4 Deliveries, D3.1–.5 and D4, for the EU sponsored ESSI Project 26538: **FME Rail**.

The **FME Rail** effort almost exclusively focused its attention on formal methods: techniques and tools as they apply to the development of operational computing systems, and in particular support for safety critical, real-time embedded systems.

Thus by "formal method" **FME Rail** rather narrowly focused on so-called formal specification and verification techniques and tools. Not, for example on the use of computational geometry and graph based optimisation technques. This latter will be remedied in the upcoming **AMORE** project [326, 30].

Contents

1 Introduction

We report on IT/DTU's work wrt. Work packages D3, D4 and D5:

- Case Studies, Section 3, WPs 3.1–3.4
- Comparative Study, Section 4, WP 3.5
- Address List, Section 5, WP 4
- Railway Bibliography, Section 6, WP 4

Section 2 prepares for Sections 3–4.

Section 6 provides evidence for Sections 2–4.

2 Methods, Techniques and Tools

By a **method** we understand a set of **principles** for *analysing, selecting* and *applying* a number of **techniques** and **tools** [incl. notations and software packages] in order *efficiently* (while adhering to a number of `conventions` relating to **`human health, property safety`** and the `environment`) a `resource-wise` [space, time, monies] *efficient* ARTEFACT (here: a computing system).

The term "formal method" is a misnomener: One may be able to formalise a technique and tools for carrying out certain technques. But it is, in general inconceivable that human ingenuity can be formalised. The principles are guide-lines that "fit in" with human ingenuity. They are usually based on pragmatics whereas formality is based on semantics and syntax. So we would prefer to use the term formal technique (and formal tool [incl. notation, ie. definition, specification, and programming languages, whether textual or graphical (as for Petri Net and StateCharts)]). Be that as it may, the misnomener, 'formal method' has got stuck ! Better would be to use precise or logical methods. Informal method is OK, imprecise or illogical is not !

2.1 Annotated List of Methods, Techniques and Tools

Currently the following alphabetically sorted list of methods, techniques and tools (software systems as well as notations) have been identified as having been or being used in understanding and developing experimental or commercial software and/or hardware (incl. equipment) solutions to railway problems.

In right margin citations we refer to (mostly) **alpha**betic references to method, technique or tool texts.

In addition we (mostly) **plain** number reference such documents which apply the itemised method, technique or tool to railway problems.

1. **[The] B Method:** [Abr96, Lan96, Wor96]

   [70, 135, 91, 90, 92, 224, 17, 225]

2. **CafeOBJ:** [DF96, Nak97, NSF, FD]

   No references yet, but sure to come !

3. **CoFI: CASL:** [oLD97, oS97, Mos97, CHKBM97]
4. **ccs:** [Mil80, Mil89]
   [245, 246, 247, 248]
5. **COLD-K:** [COL90, Jon88a, Jon88b, MdL91]
   [51]
6. **CSP/FDR:** [Hoa85, 288, Ros97, 339]
   [266, 300, 271, 270, 302, 301, 303, 337, 137]
7. **Domain Engineering:**
   [SM98, 238]
8. **The Duration Calculi:** [CHR91, CX93, CRH93, Cha93, CH93, HC94, CHX95, HG95]
   [306, 305, 68, 307]
9. **ExSpect:** [KvHV91]
   [13, 41, 263, 12]
10. **Euris:**
    [263, 132, 22, 113, 228]
11. **FOREST:** [AC91]
    [10]
12. **Graph Grammars:**
    [159, 160]
13. **HOL:** [GM93]
    [82, 334, 81]
14. **Michael Jackson's Description Principles** [Jac94, Jac95, Jac97, ZJ97a, ZJ97b]
15. **Larch:** [GHG+93, MW93]
16. **Logic:** [GHRN93b, GHRN93a, GHRN94, GHRN95, GHRN98]
    [171, 166, 169, 168]
17. **Mathematics:**
    - General: [261, 85]
    - Galois Theory: [167]
    - Graph Theory: [335]
18. **Model-checking:**
    [150, 301]

19. **μCRL:** [GP94, GP95, GvV95]

    [134, 133]

20. **Petri Net:** [Rei85, Jen85, Rei98]

    [236, 235, 12, 263, 238, 11, 13, 239, 340, 89, 218]

21. **Prolog:**

    [16, 84, 216]

22. **RAISE, RSL:** [Gro95, Gro92]

    [278, 37, 85, 121, 122, 35, 151, 26, 269]

23. **Requirements Engineering:** [ELC+98] + Jackson, item 14

24. **SMV:** [SMV]

    [174]

25. **SPRINT:** [Jon93]

    Too "new" to register. But surely there will come referenes, soon !

26. **Stålmarck's Method:** [SS90]

    [292, 133, 134, 220, 104, 102, 43, 43, 275, 47, 48, 45, 274]

27. **STeP/React:** [MP91, MP95]

    Too "new" to register. But surely there will come referenes, soon !

28. **VDM, VDM–SL:** [BJ78, Jon90, FL98]

    [144, 143, 25, 145, 99, 146, 3, 147, 152, 252, 203, 202, 4, 204, 205]

29. **Z:** [Spi88, Spi89]

    [188, 149]

2.2 Method, Technique and Tool Bibliography

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Abstract: The paper describes the FOREST approach to formal requirements specification and particularly the role of an automated theorem prover in validating specifications written in MAL, the FOREST logic. The MAL prover uses a tableau method for constructing its proofs, with rules to handle the action modalities and quantification of MAL. The authors illustrate its use in validation by using the prover to establish that a safety-critical railway-signalling specification has some desirable safety properties.

Keywords: formal specification; program verification; safety; software reliability; theorem proving.

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Abstract: The paper describes three case studies in the lightweight application of formal methods to requirements modeling for spacecraft fault protection systems. The case studies differ from previously reported applications of formal methods in that formal methods were applied very early in the requirements engineering process to validate the evolving requirements. The results were fed back into the projects to improve the informal specifications. For each case study, we describe what methods were applied, how they were applied, how much effort was involved, and what the findings were. In all three cases, formal methods enhanced the existing verification and validation processes by testing key properties of the evolving requirements and helping to identify weaknesses. We conclude that the benefits gained from early modeling of unstable requirements more than outweigh the effort needed to maintain multiple representations.

Keywords: aerospace computing; fault tolerant computing; formal specification; program verification; space vehicles; systems analysis.

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Abstract: .
This is a report on the formal definition of the CafeOBJ algebraic language, which is a modern successor of the famous algebraic language OBJ. While the equational core of CafeOBJ is just a re-shaping of OBJ3, CafeOBJ significantly extends OBJ3 by implementing several recent major developments in the area of algebraic specification, such as behavioural specification and rewriting logic. The definition of the language parallels its logical semantics based on the so-called institutions which also provide a methodological framework for structuring the presentation of the basic constructs of the language and their semantics. This report presents all basic constructs of the language together with their semantics and addressing both the programming in-the-small and in-the-large levels, but also discusses proof systems and technologies, as well as methodologies. Examples are provided all over the report as intuitive support for the definitions of the constructs and for illustrating proof techniques and methodologies.

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Abstract: methodology and of specific Larch languages for specifying C and Modula-3 interfaces. Written for practicing programmers and students, it includes both tutorial and advanced material, illustrated by numerous examples, including an extensive handbook of Larch Shared Language specifications. It also provides information on the publicly available tools that support the methodology and the languages, including LP, a powerful tool for reasoning about specifications. 250 pages, 76 illustrations; ISBN 0-387-94006-5, ISBN 3-540-94006-5; US $ 39.50.

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Abstract: Retrieval, validation, and explanation tools are described for cooperative assistance during requirements engineering and are illustrated by a library system case study. Generic models of applications are reused as templates for modeling and critiquing requirements for new applications. The validation tools depend on a matching process which takes facts describing a new application and retrieves the appropriate generic model from the system library. The algorithms of the matcher, which implement a computational theory of analogical structure matching, are described. A theory of domain knowledge is proposed to define the semantics and composition of generic domain models in the context of requirements engineering. A modeling language and a library of models arranged in families of classes are described. The models represent the basic transaction processing or 'use case' for a class of applications. Critical difference rules are given to distinguish between families and hierarchical levels. Related work and future directions of the domain theory are discussed.

Keywords: case-based reasoning; computer aided software engineering; formal specification; software reusability; software tools; transaction processing.

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Abstract: Research in requirements engineering has produced an extensive body of knowledge, but there are four areas in which the foundation of the discipline seems weak or obscure: grounding formal representations in reality, implementation bias, control of actions, and the role of domain knowledge. This article shines some light in the "four dark corners", exposing problems and proposing solutions. We show that all descriptions involved in requirements engineering should be descriptions of the environment. We show that certain control information is necessary for sound requirements engineering, and we explain the close association between domain knowledge and refinement of requirements. Together, these conclusions explain the precise nature of requirements, specifications and domain knowledge, as well as the precise nature of the relationships among them. They establish minimum standards for what information should be represented in a requirements language. They also make it possible to determine exactly what it means for requirements engineering to be successfully completed

Keywords: formal specification; nomenclature; systems analysis.

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Abstract: In engineering the requirements for a telecommunications system, the greatest obstacle to be overcome is the sheer complexity of the required behavior. We present several ways of managing and minimizing this complexity, all of proven effectiveness. Most of the specification techniques result from specific application of general requirements principles to the telecommunications domain

Keywords: formal specification; systems analysis; telecommunication computing.

3 WP 3.1–.4: Reference Case Studies

This section reports on nine individual case studies performed by IT/DTU relative to work packages D3.1–.4, as well as case studies performed in preparation for work package D3.5.

The basis for work on the last seven case study drafts briefly introduced below is [32, 33].

1. **Models of Railway Systems: Domain** 60 pages, [32]

   This and the next report, ie. [32, 33], are part of an ongoing effort to make as precise as is possible as large a part of the railway domain as (also) possible (sic !). The report thus formalises many diverse notions of railways: The railway net with its lines and stations; lines and stations with their single rail, switch (point), crossover, etc. units; the possible states — as implied by the setting of switches, signals, etc. — of these units; paths through units; routes, open and closed, through nets; state-transitions of nets; time-tables; scheduling and traffic; rescheduling; shunting and marshalling; the development and maintenance of nets (taking lines and tracks, etc. out of service, putting them, modified versions of them or new ones into service, etc.); etc.

The description of the railway net is in the form of informal synopses, narratives and terminologies and formulas. The description, at the moment, abstracts from "always current" technologies (such as how states are effected through the setting of signals — in fact there is no explicit notion of signals in [32]) — and switches (there is likewise no detailing of the various "switch gear" components and their linking to sensors and actuators etc.). These technology support descriptions are, of course, part of the domain, but represent a "concretisation" (in the hargon of computing science: 'refinement') and can and must be "added". Finally the domain description makes "absolutely" no references to computing: neither to hardware nor to software. (Only if these artefacts already are part of a supporting technology will they be part of the domain, but not at its "uppermost", intrinsics, that is: its most basic description.)

2. **Models of Railway Systems: Requirements** 62 pages, [33]

   This report "latches" onto the previous report, [32]. It attempts to illustrate how requirements to possible computing support can be "derived" from domain descriptions.

3. **Interlocking: The B Method (Draft)** [50], based on [291]

   Case study [291] is reformulated in RAISE/RSL as based on [32, 33].

   The B formulation of a problem as presented at the 3rd workshop, was reformulated in order to examine any ossible differences of methodological approach.

   The conclusion, based on rather cursory work, was that either approach, B and RAISE, is well-suited to handle the problem. The B approach is utterly elegant, whereas the RAISE approach requires more elaboration due to a "richer" specification language — the richness thus comes at a price !

4. **Interlocking: Specification and Test Case Generation for the Safety Kernel of the Naples Subway** [49], based on [1]

   Since the Italian case study had its explanatory text expressed in that fine language some effort was spent translating into English.

   It was felt that since RAISE/RSL is a more accessible approach than that used in [1] the result, [49], of this case study shows that one should perhaps be careful in choosing a generally more accessible notation, etc. In either case: The two approaches, on balance, comes out equally worthwhile and otherwise recommendable. Perhaps the work on [49] went into a few more details than did [1] — only in order to check whether the [1] document was hiding some problems. It seemed not to !

5. **Interlocking: Harmonised Interlocking Functions and Railway Signalling** [232], based on [169, 168]

   Since [169, 168] are both expressed in the classical "modern" mathematics of predicate logic, and since RAISE/RSL can be used in any combination of (albeit a three valued) logic and more model-oriented concepts, the "rewriting" of [169, 168] into [232] proved rather useful in comparing the two approaches. To some, fluent in logic, such a rewording is not worth the while, to others, more used to model-oriented expressions (B, RAISE, VDM, Z), it is worthwhile to study the differences.

Ingleby's models are faithful to established railway practice, whereas the RAISE models in [32, 33] take some liberties. Our study, [232], although it is based on different base abstractions that are [169, 168],

We belive that our work on [169, 168] has lead to a wider recognition and appreciation of the fine work done by Prof. Ingleby.

6. **SIST: A System for Checking Safety in Interlocking** [234], based on [215]

   The SIST work is expressed in algebraic terms, specifically with reference to cateorical concepts. A reformulation in RAISE/RSL was therefore deemed useful in opening up, for a wider audience, the exiting mathematical approach taken in [215].

   Ours, ie. [234], is a model of [215], an abstract implementation, as you will.

   The lesson learned is that however abstract a mathematical approach might seem at first sight, it surprisingly often yields rather general insight and techniques — especially, when as here, the apporach of [215] can be mechanised (in MAPLE).

7. **Modelling Railway Interlocking Systems** [233], based on [147]

   The approach taken by [147] is "purely" model-oriented, as is "standard" in VDM. Therefore it was felt useful to apply RAISE/RSL's more property-oriented style, ie. more algebraic approach.

   The two approaches are still ver simlar, and perhaps it can be said that our approach, as generally outlined in [32, 33] has shown its usefullness in being able to abstract, yet maintain the essence of [147].

8. **Control Process for Dwarf Signal** [231], based on [241]

   We refer also to [242, 207, 269, 337].

9. **The Automatic Railway Case** [51], based on [111]

   This document should be constrasted with the other RAISE/RSL document, [269], concerning the WARP case stuy.

   It is too early to make any conclusions wrt. comparing [242, 207, 269, 337, 51].

At least the first two reports mentioned above will enter into next phases of follow-on and –up work. Most immediately in the recently granted EU RTN (Research and Training Network) project: **AMORE: Algorithmic Modelling of Railways in Europe [326, 30].**

The size of the overall FME Rail project and especially the small size of its external funding did not allow a more definitive study

4 WP 3.5: Classification

There are two related kinds of classifications: Classification of problems to be solved using formal methods, and classication of methods wrt. their applicability to problem solution.

4.1 Problem Classification

The following is a list of problems within the railway domain for the handling of which software has been, is being or might be developed. The listing follows some logic. Earlier items of the listing deal with railway matters that must be decided upon, built, etc., before later matters can be activited: The commission of a railway line must be briefed before it can be designed, it can only be developed if a design is available, and it cannot carry scheduled trains before the line has been commissioned and before resoureces for the actual train-ride have been allocated and scheduled, etc., etc. The relationship between these matters, these concepts, form a lattice, conceptually, as well as another lattice wrt. temporal orderings of design, building, commissioning, maintenance, etc.

4.1.1 Problem Classification — A Listing

The following is a tentative list. In the upcoming **AMORE** RTN project (on Algorithmic Methods for Optimising Railways in Europe) [326, 30] the classification will serve as input to a process that should, before the end of 2000 give a more refined, detailed and annotated list.

Currently the below list lacks (albeit mostly trivial) explanations as to where and how formal techniques should and could be exploited.

A comprehensve model of "all things railways" (!), such as is being researched and developed by IT/DTU, and such as is demonstrated in rather well worked out models (see [32, 33]), such a model can and will be used as a basis for proposing requirements for software relative to each of the entries below.

It is claimed (conjectured) that a reasonably normative basis, such as suggested in [32, 33], common to software development wrt. all of the entries below, will significantly facilitate procurement of software packages that can "play together", that harmonises !

1. **Strategic Resource Management: The Long Range Analysis, Brief, Design and Development of Railways:**

   (a) **Railnet: Lines and Stations**

   (b) **Signalling**

   (c) **Rolling Stock**

   (d) **Services**

   (e) *&c.*

   The [32, 33] models (See items 1 on page 12 and 2 on page 13) show that the above and the next many items can be given a common description.

2. **Tactical Resource Management: The Medium Range Scheduling, Allocation and Deployment of Railways:**

   (a) **Time–tabling**

   (b) **Rolling Stock**

   (c) **Maintenance/Service**

   (d) *&c.*

3. **Operational Resource Management:**
   The Real–time Handling of Railways:
   (a) **Train Despatch**
   (b) **Signalling**
   (c) **Marshalling & Shunting**
   (d) **Passenger Handling (Ticketing, Reservations, Collection, &c.)**
   (e) **Freight Handling (Reservations, Acceptance, Tracing, Collection, &c.)**
   (f) **Exception Handling:**
   Accident Assessment, Relief and Recovery, etcetera !
   (g) *&c.*
4. **Overall Management Support:**
   (a) **Statistics** Feedback to Item 1 on the preceding page
   (b) **Reporting**
   (c) *&c.*

The size of the overall FME Rail project and especially the small size of its external funding did not allow a more thorough, a more definitive and more refined classification.

4.1.2 Problem Classification — Applicable Methods

We now single out some of the classified entries of the previous section and comment on which methods appear to have been used in solving software developments related to their issues. The list is short. It appears that formal methods have only been used in connection with predominantly safety related issues — although the applicability of these and other formal methods, taken together, is universal !

- **Brief, Design and Development of Railway Resources**

  No evidence was found, so far, of railway-specific use of formal techniques of the kind that this report covers.

  Applicable methods &c. are: The B Method, RAISE, VDM–SL, Z.

  - **Algorithmic Methods for Railway Optimisation:**

    But advanced computer science techniques are indeed used, in particular graph based operations analysis methods for the support of planning, sheduling and allocation activities. The **AMORE** project will cover this facet extensively [326, 30]. We refer to just a few recent reports: [54, 294, 329, 210, 211, 327].

- **Tactical Scheduling and Allocation of Railway Resources**

  No evidence was found, so far, of railway-specific use of formal techniques. But see the "Algorithmic Methods for Railway Optimisation" remark above.

  Applicable methods &c. have so far been based on operations research and logic and usually result in the use of Prolog. But as shown in [32, 33] formal techniques can play an important rôle — as will hopefully be demonstrated in the upcoming **AMORE** project.

See however Prof.Dr. Dorothea Wagner's Home Page: http://www.informatik.uni-konstanz.de/Research/projects_algo.html#projekt7 for information about an EU sponsored research, training & mobility project **AMORE: Algorithmic Modelling of Railways in Europe**.

- **Operational Handling of Railway Resources**

  A few areas have been tackled. We mention bu a few:

  - **Train Despatch**

    Although not so common a target for the use of formal techniques, one can refer to some publications and (internal) reports related to the despatch of trains: [25, 278, 85, 122, 36, 37, 121].

    Applicable methods &c. are: The B Method, CSP, Petri Nets, RAISE, VDM–SL, Z, and many others.

  - **Signalling**

    This is by far the core area of applicability, up to this moment, of formal techniques — as evidenced by the presentations given at the five FME Rail Workshops, and the sizable literature:

    [81, 135, 150, 169, 144, 16, 13, 23, 41, 263, 12, 133, 237, 43, 149, 287, 43, 90, 92, 104, 102, 112, 113, 143, 145, 146, 171, 166, 167, 245, 246, 247, 248, 275, 47, 292, 334, 301, 147, 174, 302, 321, 168, 132, 45, 239, 228, 125, 158, 123, 21, 274, 140, 285, 273, 141, 101, 260, 1, 115, 93, 20, 107, 128, 50, 49, 232, 234, 233, 196, 105, 103, 311, 195, 172, 97]

    Applicable methods &c. are: The B Method, CSP, FAST, Model checking, Petri Nets, RAISE, Stålmark's Method, VDM–SL, Z, and many others.

The size of the overall FME Rail project and especially the small size of its external funding did not allow a more thorough analysis.

4.2 Method Classification

References are given in Section 2 to literature on the below listed "bodies" of principles, formal techniques and tools.

Below we risk an assessment as to the usefulness — by railway software technologists — of the various methods. We have chosen to guide the reqader based on a few attributes and on a reasonable objective scale of three: **High, Medium** and **Low** — besides the ABC rating !

The size of the overall FME Rail project and especially the small size of its external funding did not allow a more thorough, a more definitive and more refined classification and evaluation.

- The B Method:

  - **Current Domain of Applicability:** General
  - **Documentation:** High

  - **Generality / Specificity:** High
  - **Published Evidence:** High
  - **Permanence:** High
  - **Academic/Commercial/Both (ABC):** ABC
  - **Tool Support:** Yes

- COLD–K:
  - **Current Domain of Applicability:** General
  - **Documentation:** Medium
  - **Generality / Specificity:** High
  - **Published Evidence:** Medium
  - **Permanence:** Low
    Seems to lack Academic and Industrial support.
  - **Academic/Commercial/Both (ABC):** C

- CSP:
  - **Current Domain of Applicability:** Concurrency
  - **Documentation:** Very High
  - **Generality / Specificity:** Low
  - **Published Evidence:** High
  - **Permanence:** High
  - **Academic/Commercial/Both (ABC):** ABC
  - **Tool Support:** Yes

- ESPRESS:
  - **Current Domain of Applicability:** Real–time, Embedded Systems
  - **Documentation:** Low
  - **Generality / Specificity:** Low
  - **Published Evidence:** Low
  - **Permanence:** Medium
    Seems to lack sufficient Academic and Industrial support.
  - **Academic/Commercial/Both (ABC):** BC

- ExSpect:
  - **Current Domain of Applicability:** Interlocking
  - **Documentation:** Low
  - **Generality / Specificity:** Low
  - **Published Evidence:** Low
  - **Permanence:** Low

- **Tool Support:** Yes: Based on Coloured Petri Net ([Jen85])
  Seems to lack sufficient Academic and Industrial support.
- **Academic/Commercial/Both (ABC):** BC

- FAST: Relatively new
  - **Current Domain of Applicability:** Safety Critical Systems
  - **Documentation:** Low
  - **Generality / Specificity:** Medium
  - **Published Evidence:** Low
  - **Permanence:** Medium
  - **Tool Support:** Yes
    Relatively new — too soon to judge.
  - **Academic/Commercial/Both (ABC):** BC
- FOREST: Based on logic.
  - **Current Domain of Applicability:** Safety Critical Systems
  - **Documentation:** Low
  - **Generality / Specificity:** Low
  - **Published Evidence:** Low
  - **Permanence:** Low
    Seems to lack sufficient Academic and Industrial support.
  - **Academic/Commercial/Both (ABC):** ???
- Graph Grammars:
  - **Current Domain of Applicability:** Narrow
  - **Documentation:** Low
  - **Generality / Specificity:** Very Low
  - **Published Evidence:** Low
  - **Permanence:** Low
    Relaytively isolated approach.
  - **Academic/Commercial/Both (ABC):** ???
- Logic (Non–Modal):
  - **Current Domain of Applicability:** General
  - **Documentation:** The Very Highest
  - **Generality / Specificity:** The Very Highest
  - **Published Evidence:** The Very Highest
  - **Permanence:** Eternal
  - **Academic/Commercial/Both (ABC):** AB

- Mathematics:
  - **Current Domain of Applicability:** General
  - **Documentation:** The Very Highest
  - **Generality / Specificity:** The Very Highest
  - **Published Evidence:** The Very Highest
  - **Permanence:** Eternal
  - **Academic/Commercial/Both (ABC):** AB
  - **Tool Support:** Mathematica, MAPLE, etc.
- Model Checking:

  This is a general computing science principle — used, for example in SPIN, in Stålmarck's Method's approach (FAST) and in STeP.
  - **Current Domain of Applicability:** 10^n state systems, $n \ll 30$
  - **Documentation:** High
  - **Generality / Specificity:** High
  - **Published Evidence:** High
  - **Permanence:** High
  - **Academic/Commercial/Both (ABC):** ABC
  - **Tool Support:** Of course: Can't be done without
- μCRL:
  - **Current Domain of Applicability:** Real–time
  - **Documentation:** Low
  - **Generality / Specificity:** Low
  - **Published Evidence:** Low
  - **Permanence:** Low

    Seems to lack Academic and Industrial support.
  - **Academic/Commercial/Both (ABC):** A
- Petri Net:
  - **Current Domain of Applicability:** True Concurrency
  - **Documentation:** High
  - **Generality / Specificity:** Low

    Applicable primarily to conceptual concurrency modelling.
  - **Published Evidence:** High
  - **Permanence:** High
  - **Academic/Commercial/Both (ABC):** ABC

- Logic Programming, Prolog:
  - **Current Domain of Applicability:** General. Real-time with difficulty
  - **Documentation:** Very High
  - **Generality / Specificity:** Medium
  - **Published Evidence:** High
  - **Permanence:** High
  - **Academic/Commercial/Both (ABC):** ABC
- RAISE/RSL:
  - **Current Domain of Applicability:** General
  - **Documentation:** Medium/High
  - **Generality / Specificity:** High
  - **Published Evidence:** High
  - **Permanence:** Medium/High

    Could need a bit more industrial support. Is, however, being used by a number of software houses worldwide.
  - **Academic/Commercial/Both (ABC):** ABC
- Stålmarck's Method:

  See also FAST. Natural Deduction Proof (NP) method.
  - **Current Domain of Applicability:**
  - **Documentation:** High
  - **Generality / Specificity:**
  - **Published Evidence:** Medium
  - **Permanence:** Medium/High

    Support is concentrated to a firm oart-owned by Dr. Stålmarck
  - **Academic/Commercial/Both (ABC):** BC
- STERNOL:
  - **Current Domain of Applicability:** Graphics of Rail Nets
  - **Documentation:** Low
  - **Generality / Specificity:**
  - **Published Evidence:** Low
  - **Permanence:** Low
  - **Academic/Commercial/Both (ABC):** BC

  Somewhat superceded by other approaches — and is but a language component in some current approaches.

- VDM, VDM–SL:
  - **Current Domain of Applicability:** General. Real–time with some difficulty
  - **Documentation:** Very High
  - **Generality / Specificity:** High
  - **Published Evidence:** High
  - **Permanence:** High
  - **Academic/Commercial/Both (ABC):** ABC
- Z and Z–variants: General. Real–time with difficulty
  - **Current Domain of Applicability:** General. Real–time with some difficulty
  - **Documentation:** High
  - **Generality / Specificity:** High
  - **Published Evidence:** High
  - **Permanence:** High
  - **Academic/Commercial/Both (ABC):** ABC
- *&c.*

4.3 Methodology Guidelines

It is, perhaps useful to structure the above listing while only focusing on the more generally accessible methods, techniques and tool:

- **Methods:**

  Cf. our definition of method Page 3.
  - **The B Method:** Can be strongly recommended
  - **COLD–K:** Can be recommended
  - **CSP:** Can be recommended
  - **Petri Net:** Can be recommended
  - **RAISE:** Can be strongly recommended
  - **VDM–SL:** Can be strongly recommended
  - **Z:** Can be strongly recommended
- **Techniques:**

  Cf. our definition of method Page 3. Techniques are but part of a method. Usually a technique takes care of a single step of development.
  - **EURIS:** Interlocking Specification Technique: [263, 22, 113, 228]
  - **Logic** Can be strongly recommended
  - **Mathematics (in General, other than Logic)** Can be strongly recommended

- **Model-Checking:** Can be recommended
  * **Stålmarck's Approach**
  * **SPIN**
- **STeP:** (Model checking and proof verification) Can be strongly recommended

• **Tools — Notations, Software:**

Cf. our definition of method Page 3. A tool is something that supports the use of a technique.

- **ISL:** Interlocking Specification Language: [12, 13, 41, 263]
- **Laris:** Interlocking Specification Language: [158]
- **STERNOL:** Language foir describing nets.

• **"Tool-packaged" Methods:**

- **ESPRESS**
- **ExSpect** (Coloured Petri Nets, [Jen85])
- **FAST**
- **FOREST** Automated Theorem Prover
- **μCRL**

The size of the overall FME Rail project and especially the small size of its external funding did not allow a more thorough, a more definitive and more refined classification and evaluation.

5 WP 4: FME Rail Address List

Considerable care went into constructing the below list of scientists and technologists working in the area of applying, resp. applying formal techniques to problems of railways. A few, it is estimated 3–5 on the below list has since moved to other "pastures".

Listed people have themselves either explicitly asked to enter the list or have actively participated in FME Rail Work Shops.

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6 WP 4: The FME Rail Railway Bibliography

It is known that the current version of the approximately 340 entry strong bibliography has some 20 or so duplicates. These will be sorted out as the current bibliography is being exploited in follow-on R&D activities.

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Abstract: The paper describes the FOREST approach to formal requirements specification and particularly the role of an automated theorem prover in validating specifications written in MAL, the FOREST logic. The MAL prover uses a tableau method for constructing its proofs, with rules to handle the action modalities and quantification of MAL. The authors illustrate its use in validation by using the prover to establish that a safety-critical railway-signalling specification has some desirable safety properties.

Keywords: formal specification; program verification; safety; software reliability; theorem proving FOREST.

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Abstract: This paper describes a study on simulating and analyzing interlocking specifications in the Interlocking Specification Language (ISL), using the tool ExSpect. ExSpect is a toolkit based on the theory of coloured Petri nets. An approach to translating ISL to ExSpect is suggested. Experimental results of simulating and analyzing part of an ISL specification in ExSpect are discussed. ExSpect seems to be useful for simulating and analyzing ISL specifications. Furthermore, several interesting topics for future research are identified ExSpect.

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Abstract: This paper evaluates the ability of ExSpect, a toolkit for simulating and analyzing complex distributed systems using colored Petri nets, to analyze ISL specifications for railway interlockings.

Keywords: railways; colored Petri nets; complex; Computational linguistics; Computer simulation; digital simulation; Distributed computer systems; distributed systems; Electric railroads; ExSpect; formal specification; Interlocking signals; Interlocking specification language; ISL specifications; Railroad traffic control; railway interlockings; software toolkit; digital simulatio ExSpect.

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Abstract: During the last years there has been a rapidly growing interest in the transportation and logistics domain for systems based on artificial intelligence techniques. This paper proposes a practical approach to an actual planning problem of a railway interlocking. A railway interlocking is defined as a system that is used to guarantee safe train movements. Often railway interlockings are systems of relays controlled by computer equipment and/or human operators. In order to adapt to a dynamic environment without creating dangerous situations, a formalism for describing safety requirements and interlocking behaviour is needed. This study intends to show why a logic programming language is a strong candidate for handling such a formalism. This work exploits the advantage of using external procedures written in other languages which is supplied by many software manufacturers of Prolog systems. The openness of Prolog makes it a powerful language to describe the complex environment of a railway system.

Keywords: formal specification; logic programming; planning; PROLOG; rail traffic; safety; traffic control; transport control Logic Programming, Prolog.

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Abstract: The east-central region of Florida, including Orlando, has experienced extremely dynamic growth in the past two decades. This has placed a continual strain on the existing transportation network. The region's primary transportation artery, Interstate 4, is experiencing much of this strain. In order to alleviate the congestion on I-4 and prepare for the future growth of the region, the State of Florida Department of Transportation (District 5) is preparing a comprehensive master plan to guide future improvements to I-4. Alternatives vary in scope from the simple addition of lanes, to the addition of extensive high occupancy vehicle lanes, park and ride facilities, and urban rail systems.

As alternatives have been developed, GIS has been introduced as a means of evaluation to assist in deciding which ones best meet the overall needs and concerns of the region. It is the purpose of this paper to describe the alternatives and illustrate how GIS is aiding planners in this complex decision making process. Two primary GIS applications will be described: the determination of wetland impacts and right-of-way acquisition costs. Each application will include a discussion of database creation using high resolution aerial photography, the overlay analysis, final reporting procedures, and benefits of using GIS versus previous methods of evaluation.

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Abstract: It is well known that a fundamental problem in embedded control systems is the verification of the safety requirements. Formal methods and related support tools can successfully be applied in the formal proof that a system is safe. However, the complexity of real systems is such that automated tools often fail to formally validate such systems. A typical case is when "state explosion" problems arise. We show some "abstraction techniques" to make the problem of safety requirements validation tractable by current tools. These abstraction techniques have been defined inside a verification methodology that has been tested on the specification of a railway computer based interlocking signalling control system. The conditions under which this methodology can be applied to systems in different application areas are finally discussed.

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Incomplete draft — the result of one week's work over Chinese New Year 1994!

FME Rail Annotations:

- **Rail subject:** Train despatch and traffic monitoring.
- **Principles, techniques, tools:** Domain and requirements engineering, software architecture, VDM.
- **Notes:** Proposes a concrete solution to the display and manipulation of (abstractions) of data screen layouts for train running maps.

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Abstract: This document shall serve to inform a larger audience of the goals of the AMORE project as seen from and hopefully discharged by the Department of Computing Science, the Technical University of Denmark (DCS/DTU). It sets the goals for the AMORE part to be handled by DCS/DTU. The issue of the present version of this document shall thus also serve to inform young, aspiring candidates from abroad Europe (and outside Denmark), pre– or post PhD researchers who will work at DCS/DTU as financed by the AMORE grant. very many and diverse optimisation problems and solutions by means of a carefully tuned set of coherent **Abstract Models of Railway Planning & Handling (AMoRPH)**. This Synopsis is about that latter project methodological approach as it is "anchored" at the Dept. of Computing Science, The

Technical University of Denmark. semi-formalises such notions as optimisation, scheduling, allocation, and strategic, tactical and operational planning before it considers a taxonomy of railway optimisation issues. The document also exemplifies a "tiny" informal and formal description of the kind that the AMORE project component AMoRPH will base its further work on. formalisations will illustrate the methodological approach talen by DCS/DTU: formal specification and (but not illustrated here) formal (and rigourous and systematic) verification.

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Torso: The report in grossly incomplete.
With contributions from: Jakob Braad, Jon Fuglsang, Karin S. Mogensen and Ulrik Svanlund.

Abstract:
This report presents a solution to the problem presented by the organisers of a Case Study Workshop in connection with "Coordination'97: The Second Intl. Conference on Coordination Models and Languages, Berlin, September 4, 1997".
The solution covers three stages of development: A domain theory of railway systems, a set of requirements definitions, a computing systems architecture and a program organisation. All stages are both informally and formally described in the RAISE Specification Language, RSL, and correctness relations are formally expressed using the RAISE Method Implementation Relation.

Keywords: domain engineering; requirements engineering; railway systems; RAISE; RSL.

FME Rail Annotations:

- **Rail subject:** Railway domain.
- **Principles, techniques, tools:** Domain engineering: intrinsics, RAISE, RSL.
- **Notes:** The approach of this report is suggested as indicative, i.e. as a model for one of a set of normative descriptions of the domain of railway systems.
  DB intends to have the present report reworked rather completely during the winter of 1998/1999 and the spring of 1999.

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FME Rail Annotations:

- **Rail subject:** Scheduling, rescheduling.
- **Principles, techniques, tools:** RAISE, RSL.
- **Notes:** Main author: Chris George.

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Presented at KICS'94: The Kunming (Yunnan, PRC) Intl. CASE Symposium, Nov. 1994.

FME Rail Annotations:

- **Rail subject:** Railway station management, rail topology, signalling.
- **Principles, techniques, tools:** Domain engineering: intrinsics, RAISE, RSL.
- **Notes:** Somewhat dated model.

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Abstract: An interlocking is a system used at railway yards for guaranteeing safety of train movements. This report opens a series of studies on tightly related specification languages for interlockings. These languages together are called ISL. Interlocking Specification Language. ISL is designed by P. Middelraad of the Dutch railway company, NS, de Nederlandse Spoorwegen. NS have developed a symbolic intermediate tool interface language, IDEAL, for ISL. IDEAL is the Interlingua for all men and machines using ISL. This report introduces interlockings, the long-term goals of the ISL project, and, as a first step, we present the syntax and static semantics of IDEAL in ASF+SDF, an algebraic specification formalism. Several improvements of IDEAL are suggested ExSpect.

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Keywords: railway interlocking, formal specification; formal verification; hardware description languages; railways; telecommunication computing; theorem proving Stålmarck's Method.

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Keywords: CAD; computerised control; formal languages; formal logic; formal specification; high level languages; railways; real-time systems; signalling; specification languages **RaCoSy Repository**. ccs.

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Keywords: safety-critical software; signalling; traffic control; traffic engineering computing **RaCoSy Repository**. The B Method.

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FME Rail Workshop # 4, volume # 4 of *FME Rail Workshop; Stockholm, Sweden.* FME: Formal Methods Europe, Banverket, Falun, Sweden, May 12–14 1999. ERRI, The Netherlands. **RaCoSy Repository**.

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Abstract: Track maintenance work was planned using GA and GP, with profit as the optimisation criteria. The results where compared with an existing determinstic technique. It was found the GP method gave the best results, with the GA method giving good results for a short section (10 miles) and poor results for a long section (50 miles). 12–14 September 1995, Halifax Hall, University of Sheffield, UK see also http://www.iee.org.uk/LSboard/Conf/program/galprog.htm.

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Abstract: At the Dutch station Hoorn-Kersenboogerd, computer equipment is used for the safe and in time movement of trains. The computer equipment can be divided in two layers. A top layer offering an interface and means to help a human operator in scheduling train movement. And a bottom layer which checks whether commands issued by the top layer can safely be executed by the rail hardware and which acts appropriately on detection of a hazardous situation. The bottom layer is implemented with a programmable piece of equipment namely a Vital Processor Interlocking[1] *(VPI)*. This paper introduces the most important features of the *VPI* at Hoorn-Kersenboogerd. This particular *VPI* is modelled in μCRL. Furthermore, the paper touches upon correctness criteria and tool support for *VPI*s, and suggests ways for verification of properties of *VPI*s. Experiments show that it is indeed possible to efficiently verify these correctness criteria.

Comments: The analysis of this station was based on a Prover developed by Jan Frison Groote. The prover in question is based on Stålmarck's method μCRL.

[134] J.F. Groote, S.F. van Vlijmen, and J.W.C. Koorn. The safety guaranteeing system at station Hoorn-Kersenboogerd. In *COMPASS '95. Proceedings of the Tenth Annual Conference on Computer Assurance (Cat. No.95CH35802); Gaithersburg, MD, USA*, pages 57–68. IEEE, New York, N.Y., USA, 1995. See [133].

[1] VPI and Vital Processor Interlocking are registered trademarks of the General Railway Signal Company.

Abstract: At the Dutch station Hoorn-Kersenboogerd computerized control is used for the safe and in time movement of trains. It can be divided in three layers. A top layer assisting an operator in scheduling train movement. A bottom layer with hardware that can monitor and change the state of the railway. And an intermediate layer mainly checking whether commands issued by the top layer can safely be executed by the bottom layer. The intermediate layer is responsible for the safety of the railway. It is implemented with a programmable piece of equipment namely a Vital Processor Interlocking (VPI). This paper introduces the most important features of VPIs and models them using the process algebraic language μCRL. The form of correctness criteria of VPIs is described and these criteria are classified in the categories STATIC, JUST and NEXT. We verify the correctness criteria by transforming both the program and the criteria to propositional logic. We describe our experiences with tool support, both for the transformation and for proving formulas. Experiments show that it is also rather straightforward to verify correctness criteria on larger railway yards.

Keywords: formal logic; formal specification; formal verification; railways; safety-critical software; traffic information systems.

Comments: The analysis of this station was based on a Prover developed by Jan Frison Groote. The prover in question is based on Stålmarck's method μCRL.

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Abstract: Railway signalling manufacturers have been designing safety-critical software for around ten years (1984-94). This software is crucial for interlocking systems and speed control systems. The techniques used by the railways and the manufacturers were dissimilar in the past because of the heterogeneousness of signalling equipment and exploitation rules among different countries. Recently some efforts have been underway at the European level to harmonize the processes and methods for cross-acceptance of safety-critical software between nations. The work of the IRSE Technical committee and the CEN/CENELEC WG A1 are presented. Formal specifications and formal proofs seem to be considered as one of the best techniques to use in that field. Some of the systems that we have produced using them are presented.

Keywords: formal specification; rail traffic; railways; safety; software reliability; traffic computer control The B Method.

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Abstract: A recent study on level crossing safety is reported. The study employed three different approaches: a survey of drivers' attitude to the level crossing, quantitative estimation of accident risk from characteristics of level crossings, and improvement of crossing design from the human factors point of view. The results have been utilized by railway companies and police authorities in safety campaigns, driver education, safety investment, and improvement of warning systems for level crossings.

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Abstract: Presents a VDM model of a real-life railway interlocking system, and describes how this model is validated through simulation in ML. The model development illustrates how concepts may be captured for a non-trivial system. The steps from a predicative VDM model to an executable ML program are also outlined. The importance of validation by simulation is highlighted by giving two equally plausible safety requirements for the system and the end user's reaction to the simulation. For safety reasons, we find it important that the model also can form the basis for formal program development, where the correctness of the program with respect to the specification can be formally verified. Therefore, we advocate to make a model which can be used for simulation as well as formal program development.

Keywords: digital simulation; formal verification; railways; safety-critical software; Vienna development method **RaCoSy Repository**. VDM, VDM–SL.

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FME Rail Annotations:

- **Rail subject:** Railway interlocking.
- **Principles, techniques, tools:** VDM.
- **Notes:** Simulation, end-user validation.

RaCoSy Repository. VDM, VDM–SL.

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Abstract: The increasing internationalization of the transportation market and the rising pressure of competition characterize the transportation sector today. This demands a high degree of adaptability with the ability to react quickly to the market and to technological changes. For railways this means meeting the information requirements along the transportation logistic chain. Data interchange becomes unavoidable also in passenger traffic. This paper presents some examples of electronic data interchange in the field of railway traffic.

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Abstract: This paper discusses the preparation of a requirements specification for a railway signalling interlocking system using the Z notation. It then reviews the use of the specification project as a case study within the Esprit III project, CASCADE, which aims to develop a generic assessment method for safety critical software-based systems.

Keywords: formal specification; railways; research initiatives; safety-critical software; signalling; specification languages; traffic engineering computing **RaCoSy Repository**.

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Abstract: This study presents new risk analysis tools and demonstrates the feasibility and applicability of these tools in the design verification of railway interlocking control systems and deadlock prevention in automated manufacturing systems. Our verification methodology consists of the following stages. First, we analyze the rules executed by the controller and extract a state machine model of the controller. Second, we compose safety, reliability, and operability system specifications using a propositional temporal logic. Finally, we use the model checker to check the state machine model of the system against its requirements. The verification approach allows an exhaustive search of all possible behaviors and scenarios. We verified two real railway interlocking control applications with 125 and 452 constraints respectively. Checking two opposing signal protection specifications involving 3 signals ranged between 74 and 1223 seconds depending on the size and the complexity of the interlocking. Traditional verification methods typically require several person weeks.

Keywords: CAD/CAM; computer integrated manufacturing; concurrency control; formal specification; formal verification; industrial control; risk management; temporal logic Model Checking.

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FME Rail Annotations:

- **Rail subject:** Simple, single railway line.
- **Principles, techniques, tools:** RAISE, RSL; domain model, safety requirements, software design, distributed control.
- **Notes:** Stepwise development, correctness proof arguments.

RaCoSy Repository. RAISE/RSL.

[152] A.E. Haxthausen and J. Peleska. Formal Development and Verification of a Distributed Railway Control System. In *FME Rail Workshop 1*, DK–2800 Lyngby Denmark; P.O.Box 340440, D–28334 Bremen, Germany, 1998. Dept. of IT, Techn. Univ. of Denmark; BISS, Bremen Univ. See also: [151]. In: [206].

FME Rail Annotations:

- **Rail subject:** Simple, single railway line.
- **Principles, techniques, tools:** RAISE, RSL; domain model, safety requirements, software design, distributed control.
- **Notes:** Stepwise development, correctness proof arguments.

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Keywords: scheduling, shortest path, cran, galvanization, production planning, transportation.

Abstract: In this paper we consider the problem of finding a feasible routing for one-dimensional transport systems. This problem arises as a subproblem in production planning, when a mono-rail crane with several crabs is part of the production lane. Practical restrictions like finite speed of crabs and a minimal distance between crabs lead to a special routing problem. We show that this problem corresponds to the geometric problem of covering segments with angle-restricted curves with the additional constraint that all curves have at least distance 1. We prove that this question can be formulated as a shortest path problem. Finally we discuss how the presented algorithm can be used as a module for a greedy-algorithm solving a no-wait scheduling problem.

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[158] M. Hollenberg, J.F. Groote, and S.F.M. van Vlijmen. *Laris 1.0 Language for Railway Interlocking Specifications*. Utrecht. Referenced in [194] **RaCoSy Repository**.

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Abstract: In this paper we develop in three phases a railway control system. We are mainly concerned with the software architecture of the control system and its dynamic evolution; we do not discuss here the implementation details of the components forming the control system. First, we informally discuss our design proposal for the architecture of the control system: a hierarchy of controllers whose leaves are local controllers connected in a network that mimics the underlying railway topology. Second, we formally define by means of particular graph grammars a style of software architectures for the railway control system consisting of two complementary views and ensuring several desirable properties by construction. The dynamic evolution of the architecture is modelled by a set of coordination rules which define graph transformations and are verified with respect to to the graph grammar. Third, using a coordination rule as a formal specification of a dynamic modification of the railway control system, we derive its implementation in ConCoord, a programming environment for concurrent coordinated programming. With regard to software engineering, the two first phases belong to the system design while the third one forms the first implementation step.

Keywords: formal specification; graph grammars; rail traffic; railways; software engineering; traffic control; traffic engineering computing **RaCoSy Repository**. Graph Grammars.

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Abstract: The development of a computer-based graphics display for the Channel Tunnel Rail Link is outlined. The specification of the graphics display package is shown to be a trade-off between flexibility in terms of running the package on standard microcomputers independently of proprietary software, the constraints of present computer graphics technology and the costs of producing suitable graphics images. The use of computer-based graphics is seen to offer a flexible and innovative method of communicating the details of railway schemes to a non-technical audience, particularly in terms of illustrating the concepts and ideas underlying railway projects and the measures undertaken to reduce environmental impacts. The use of the package has resulted in more structured, informed and constructive discussions within the consultation programme.

Keywords: CAD/CAM; railways **RaCoSy Repository**.

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Abstract: The following topics were dealt with: AAMP5 microprocessor verification; architectural specification of an avionic subsystem; software requirements analysis; formal methods; C++ library for specification implementation; system critical flight software verification; industrial design verification; timing analysis of real-time systems; real-time reactive systems specification; finite state machines; reactive systems software; **railway signalling**; and LOTOS specification.

Keywords: formal specification; formal verification; hardware description languages; real-time systems; specification languages **RaCoSy Repository**.

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Abstract: In the rail transportation industry competitive pressure has led to the increased use of COTS (commercial off-the-shelf equipment in safety critical systems), making it imperative that we extend proven safety techniques to COTS based systems as well. To this end, we have developed the Vital Framework (V-Frame), which is used to develop a safety critical platform from COTS hardware and software. The key technologies in this framework are formal methods, information redundancy, a proprietary data format, and a concurrent checking scheme. Combining these technologies results in a real time, checkable correctness criterion that is a signature of the application's algorithm structure and is independent of both the hardware and the operating system. V-Frame's most significant attribute is that the fail safe properties of applications do not require the firmware to be correct: the application will operate in a fail safe (or vital) manner even if there are design faults in the operating system and/or the hardware fails. This does not mean that the application does not have to be correctly specified and designed. Formal methods are appropriate in the design of safety critical COTS systems because a generic processing environment is analogous to a formal system: it is designed to apply well defined transformation rules to inputs (7 Refs.).

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Abstract: Interlockings-systems which control railway signals-are modeled as situated automata holding in memory an image of their trackside environment. Interlocking functionality is generic, but each interlocking consults a geographic database which specifies the topography of its environment. A 'calculus of hazard' comprising a theory of trackside geography and generic state of trackside environments is set up using a predicate calculus based on incidence relations. The calculus is sufficiently expressive for the articulation hazard defence rules-which are obtained from a typical IEC fault modes and effects analysis (FMEA)-free of area-specific reference. Safety of an interlocking is formulated as an NP-complete proof problem expressing the invariance of a set of hazard defence predicates of the calculus. A scaleable approach to this proof problem is developed by representing a signalling area as a set of weakly interacting localities of low combinatorial complexity. The approach uses Galois connection tools borrowed from formal concept analysis.

Keywords: computational complexity; failure analysis; formal logic; formal specification; geographic information systems; rail traffic; signalling; traffic control Logic (Non–Modal).

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FME Rail Annotations:

- **Rail subject:** Railway interlocking.
- **Principles, techniques, tools:** Geographic Data Language, logic, process algebra, SMV.
- **Notes:** .

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Abstract: In a large scale real time control system, functions of subsystems differ slightly although they seem to be identical. Functions change when hardware is replaced or when the function itself is upgraded. If the standard system is generated by merging the differences and is installed then to each subsystem, subsystems become different with maintenance being carried out in each subsystem to fit its operational conditions. Furthermore, subsystems are distributed in a wide area. Software maintenance therefore becomes very difficult. The paper describes a distributed management for software maintenance in the Tokyo metropolitan area railway system. This management has two phases: generating programs for making maintenance easy and executing programs for increasing the reliability of the system. There it contributes to the effectiveness of maintenance and increases the reliability of the total system.

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Abstract: Video-based Training Course on the Z Specification Language. The course consists of 5 videos, each of approximately one hour duration, together with supporting texts and case studies. The course is aimed software engineers in industry who wish to take a look at formal methods. It is specifically designed to give skills in *reading* Z specifications. The material is also suitable for use in academic institutions where students are to be introduced to Z.

There are 5 video tapes, each about 1 hour long. The tapes contain material on supporting mathematics followed by a tutorial specification showing the mathematics in action. Each part of the course is accompanied by a booklet containing the specifications discussed on the tapes with annotations. The contents is as follows:

1 An introduction to sets. Specifying a (very) simple Security System.

2 Functions. Specifying a simple Banking System.

3 Sequences. Modelling queues at a petrol filling station.

4 Relations. Specifying an e-mail system.

5 A review of the Z mathematical tool kit. Three further written specifications to practice reading skills: Modelling Family Relationships; Specifying a Lift (elevator) System; Railway Signalling.

Formats: VHS(PAL) for UK, Europe, Australia, etc.; VHS(NTSC) for American continent; SECAM for France & Russia. Other formats could be made available on request. Further details, including free preview material, are also available. For information, please contact: Anthony Meehan, School of Engineering Information Technology, Sheffield Hallam University, Pond Street, Sheffield S1 1WB, UK.

[263] L.H. Oei. Pruning the Search Tree of Interlocking Design and Application Language Operational Semantics. Technical Report P9418, University of Amsterdam, Programming Research Group, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands, November 1994.

Abstract: An interlocking is a system used at railyards for guaranteeing safety of train movements. This paper succeeds the study on the syntax and static semantics of tightly related graphical specification languages for interlockings. These languages together are known in NS documents as the Euris method. The Euris method has been designed by P. Middelraad of the Dutch railway company, NS, de Nederlandse Spoorwegen[2]. It concentrates on a graphical definition of Railway Interlocking by means of the so called Logic Sequence Charts, short LSCs, which is a derivation of the well known Flow Charts. NS have already developed a symbolic intermediate tool interface language, IDEAL to automate processing of LSC specifications. IDEAL, Interlocking Design and Application Language, is therefore effectively used as an Interlingua within the Euris-Simulation project. A feasibility study of strategies of translations of IDEAL to the ExSpect simulation specification language is made. ExSpect, Executable Specification Tool—a formalism based upon Petri Nets—, would mean a first step toward proof theoretical correctness of the Euris method. As in the previous study, we have made use

[2] The project we are involved in we sometimes refer to as ISL: Interlocking Specification Language.

of the Algebraic Specification Formalism and the Syntax Definition Formalism which has been integrated in the ASF+SDF Meta-environment, for this purpose. The major question addressed is whether it is possible to apply full automated transformation of manageable complexity of IDEAL to ExSpect, without losing the LSC operatonal semantics, and at the same time gain the Petri Net invariants Petri Net, ExSpect.

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Abstract: This paper describes a formal approach to requirements specifications for railway safety critical software systems and their formal safety definitions. Considering the programs and the data in a software system as the axioms and the inference rules in a formal system, we can claim that the system is safe if and only if, within the formal system, we can prove theorems that are equivalent to the safety requirements. This approach has many advantages. First, a specification is rigorous so that any ambiguity may be excluded. Secondly, specifications can be compared easily so that differences between systems will be clearer than in a natural language. This would be very useful for confirming interoperability for two systems. Thirdly, there may be systems or methods to mechanically convert a formal specification into an executable program. These are the reasons we started this investigative study. Part of an on-going study, this paper looks into the research carried out in various places abroad and seeks to clarify the underlying principle, and in particular its safety requirements. Some indications of our possible future studies are included.

Keywords: formal specification; rail traffic; railways; safety-critical software; traffic control; traffic engineering computing **RaCoSy Repository**.

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Abstract: We report experience with the construction of a system supporting several concurrent programming abstractions (futures, Linda, CSP, time-wap and paralations) and of an experiment (in an earlier system) in which time-warp was modelled in Linda. As a result of this work we can now cast these competing abstractions in a common framework by the use of classes. This leads to the concept of the generic scheduler. As an application of these techniques, we discuss a railway simulation which uses Linda and time-warp CSP.

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France, September 22–24 1999. TERMA Electronik, Denmark. **RaCoSy Repository**. RAISE/RSL.

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Abstract: We describe the theoretical foundations for the VVT-RT test system (Verification, Validation and Test for Reactive Real Time Systems) which supports automated test generation, test execution and test evaluation for reactive systems. VVT-RT constructs and evaluates tests based on formal CSP specifications (C.A.R. Hoare, 1985), making use of their representation as labelled transition systems generated by the CSP model checker FDR. The article provides a sound formal basis for the development and verification of high quality test tools; since, due to the high degree of automation offered by VVT-RT, human interaction becomes superfluous during critical phases of the test process, the trustworthiness of the test tool is an issue of great importance. The VVT-RT system will therefore be formally verified so that it can be certified for testing safety critical systems. The article represents the starting point of this verification suite, where the basic strategies for test generation and test evaluation used by the system are formally described and verified. VVT-RT has been designed to support automation of both untimed and real time tests. The article describes the underlying theory for the untimed case. Exploiting these results, the concepts and high level algorithms used for the automation of real time tests are described in a second report which is currently prepared (J. Pelaska, 1995). At present, VVT-RT is applied for hardware in the loop tests of railway and tramway control computers.

Keywords: formal specification; program testing; program verification; real-time systems; safety-critical software CSP.

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Comments: Uses Prover Technology **RaCoSy Repository**. Stålmarck's Method.

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Abstract: The VODIS project is focused on the area of speech-based interfaces to information systems accessible via the public telephone network. The key features of this environment are a highly restricted topic domain, goal oriented dialogue, continuous speech from a small (150 word) vocabulary, naive untrained users and highly variable recognition rates. Our dialogue design strategy has been motivated by two major requirements: (i) to provide a habitable user interface and (ii) to give direct support of the speech recognition process. Our implementation strategy has been to use the frame approach using our special purpose programming language UFL. For (i) we have been guided by two influences. Firstly, we have analyzed real data obtained from transcripts of an existing (human) information service: the British Rail Timetable Enquiry Service. Secondly, we have adopted a formal measure of "goodness" based on minimisation of transaction time. For (ii), we have developed an adaptive strategy whereby the user responses are syntactically constrained. When recognition is good, user inputs are relatively unconstrained. When performance is poor, questions to the user are made much more specific ultimately to the point where only single word answers are invited and accepted. The purpose of this chapter is to review our overall system design strategy from the point of view of dialogue control and reflect upon the lessons learnt.

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Abstract: This paper reports the design, implementation and results of a trans-European scale transportation accessibility model. This study reports only the results of the railways portion of the model, which includes multiple categories of lines within the transportation hierarchy. The rail network was digitized over the road network and the design considers not only the railways but also the possibility of taking another means of transport in order to access the train. Implementation of the model used indicators of 'absolute accessibility' similar to those reported in Gutierrez et al. (EGIS '93), except for important differences resulting from enhanced network analysis capabilities in the most recent version of the GIS software. Analysis includes construction of isoaccesibility contours zones showing net increase in accessibility and differences maps.

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Abstract: In the system test centre described, railway electronic interlockings are comprehensively tested and verified. Until now, this could only be done on site, at the original system for the customer. Configuration of the test centre allows simulation of every route system in service which is available as real-time simulation. In the system test centre, the system checks for new installations as well as for reconstructions, internal acceptances and fault processing are carried out. System checks consist of a function integrity test, detection of time response and interface and stress tests. By this procedure, faults in the software can be detected and corrected before delivery of the interlocking. The quality of the product is increased and additional costs arising for the concerned railway authority at a later stage due to limited availability are prevented. When interlockings are reconstructed, the new data can be prechecked so that the change on site can be realized much faster than until now. Consequently, operational inconveniences can be reduced to a minimum.

Keywords: engineering; digital simulation; program testing; program verification; rail traffic; railways; real-time systems; software reliability; traffic control; traffic engineering computing **RaCoSy Repository**.

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Keywords: optimisation; rail traffic; traffic control.

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Abstract: A time table system records the departure and arrival times at many stations of many trains. A train journey often involves more than one train trip. Given several possibilities of journeying from one station to another, especially for long distance journies over a wide area rail net with may different paths leading, and/or many different kinds of train types running between these stations, the issue tackled in this paper is that of finding minimum time journies. Heuristic techniques, based on Dijkstra's shortest path algorithm, are explored in the light of a "snapshot" of half a million customer queries.

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Abstract: In this paper development of a scheme for the newest solid-state interlocking system named PRIME, is introduced, Interlocking systems need different specifications on each station. The interlocking tables form most of that specification. By utilizing this tool, the railway signal engineer is able to manage a large number of data easily and efficiently, and compiles interlocking data from the interlocking tables for PRIME. Interlocking function which is required for fail-safe control, is dependent on interlocking data. Therefore fault avoidance of interlocking data is indispensable. It is for this reason that we utilized software design diversity for construction of this tool. We have four phases of the design diversity in the software life cycle: Phase-1 - diversity data input of interlocking table and geographical data; Phase-2 - decompile of interlocking database; Phase-3 - interlocking data compile and interlocking functional test; and Phase-4 - diversity compile for track remodeling support data.

Keywords: control.

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FME Rail Annotations:

- **Rail subject:** Railway signalling, interlocking.
- **Principles, techniques, tools:** CSP, model checking, refinement.
- **Notes:** Safety.

RaCoSy Repository. CSP, Model Checking.

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Abstract: This paper represents how GIS was used in support of a marketing initiative to increase ridership on the Central Light Rail Line in Baltimore, Maryland. A primary objective of the initiative was to develop a marketing strategy which identified geographic locations in the region in which to target marketing efforts. GIS was identified as an ideal tool to perform spatial analysis to yield the desired results. The analysis was performed by importing several existing data sources into the GIS. These data sources included passenger survey data, census data, and local demographic forecasts. Using GIS, it was possible to ultimately isolate individual transportation analysis zones which contained the greatest potential for new ridership. GIS also created dramatic color thematic maps used to present the findings of the study to senior management.

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Abstract: In the paper are presented the feasibility study and work on the project for the introduction of the EDI system at the Port of Koper based on the EDIFACT standard and also plans to introduce the EDI transactions through three phases. The Port of Koper has started the project to connect its business partners through the EDI system. The aim of project in the first phase is to communicate messages about work orders (dispozicija) which is the main source of information for the short term planning. The data are collected mainly from shipping agents, forwarding firms, railway companies

and trucking companies. Since the Port of Koper is a customs free zone the goods are under strict Customs surveillance so the data must also be available for customs inspection and control. The present state of the international EDIFACT standard is offering some messages to be used for the purpose of planning at the Port of Koper. The most suitable is the IFTMFR(International Forwarding and Transport Message Framework) a message framework consisting of six different messages. The preliminary study has shown that some segments have to be added to the IFTM messages to suit the needs of Port of Koper and ita partners. The CUSDEC (Customs Declaration Message) and CUSRES (Customs Response Message) messages are also important to this project but the customs documents currently in use in Yugoslavia are not prepared according to those standards
The first part of project, which has to be operational by the end of the first quarter of the year 1992, will cover the introduction of the standard message for the data interchange between the Port of Koper and its business partners with all necessary coding and organizational instructions. The system will also cover the feed- back information about work which has been accepted and planned at the Port of Koper. In the next phase of the project, to be commenced after the first phase has started, the EDI system will also cover the information about ships coming and going to the port, work completed and direct data interchange with the railways.

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Keywords: data visualisation; microcomputer applications; railways; traffic engineering computing; transportation.

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Keywords: limit distribution, random walk, Airy function, path length.

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Abstract: Philadelphia-based Consolidated Rail Corp. (Conrail), a $3.5 billion corporation, is applying geographic information systems (GIS) technology to position itself as an "information-based" company, where employees find and use information to improve processes and support decision making via their desktop PCS.

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Abstract: Given a set of train journies where each train journey visits a number of stations the problem tackled in this paper is that of selecting a minimum set of stations such that each train journey (in the given set) visits at least one of these selected stations.

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Abstract: This report details the initial analysis of the safety-critical design task used as a case study for the project; that of data preparation for Solid-State Interlocking, a microprocessor- based control system for railway signalling. Hierarchical Task Analysis is used to study task structure, staff allocation and the impact of computer automation of parts of the task.

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[336] T. Wood. Living with complexity (in railway software engineering). In *Living with Microprocessor Controlled Traction Systems*, IEE Colloquium (Digest No.056), pages 3/1–4, 32 pages. IEE, 1990.

Abstract: In this paper, the author argues that there are no reasons why the railway industry should be different from other industries with respect to its attitude to software engineering. For some years (perhaps about five) almost every new large railway control project has been applying structured techniques, mainly because of earlier disasters with other software methods. The author shows that we are now beginning to see them applied to smaller developments (with one or two software engineers) with good results. Whereas three years ago, one saw little evidence of these techniques, the author highlights how we are now beginning to see them being taken up by the railway industry.

Keywords: rail traffic; software engineering; structured programming; traffic computer control.

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Workshop venue: Canary Wharf, London Docklands, England.
Organised by Formal Systems Ltd., Oxford. Hosted by London Underground.

Contents: [151, 301, 147, 174, 96, 225, 124] as well as: A Tutorial: The RAISE Development Method (Dines Bjørner based on 1994 material by A.E. Haxthausen), A Tutorial: CSP — Communicating Sequential Processes (Jim Woodcock) **RaCoSy Repository**.

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7 Resource Assessment

- Prof., Dr. Dines Bjørner: Total more than 6 man-months
  - ID/DTU coordinator since Feb.1998
  - D3.1–.4: Local Case Studies: more than 2 man-months
    [32, 33, 50, 49, 232, 234, 233, 231, 51]
  - D3.5: Classification of Case Studies 15 days

- Programme Coordinator of the Stockholm Work Shop — more than 10 days
- Active participant in all five ME Rail Work Shops:
  * T2.1: RAISE Tutorial FME Rail # 1: Breukelen [26] — more than 5 days
  * T2.1: RAISE Tutorial FME Rail # 2: London [28] — more than 5 days
  * Lecture FME Rail # 3: St.Pölten [29] — more than 5 days
  * Lecture FME Rail # 4: Stockholm [50, 49, 232, 234, 233, 231, 51] — see eralier item
  * Lecture FME Rail # 5: Toulouse [32, 33] — more than 5 days
- Work on a World–wide[3] R&D Project Proposal: **TRaIn: The Railway Infrastructure** [29]
- D4,1: Work on Address List — more than 20 days
- T4.3: Misc., Visits, etc. — 5 days
- WP4: Work on Bibliography — more than 20 days
- Wrote this Report

• Assoc.Prof., Dr. Anne E. Haxthausen — N_1 man-months

• Ms. Karin S. Mogensen: — N_2 man-months

Co-investigator and –author: [50, 49, 232, 234, 233, 231, 51]

• Mr. Jakob Braad: — N_2 man-months

Co-investigator and –author: [50, 49, 232, 234, 233, 231, 51]

• Mr. Peder la Cour: Maintenance of Bibliography — N_3 man-months

8 D3.1–.4: Case Study Reports

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9 Conclusion

- The man power spent by IT/DTU far exceeds that planned for in the contract.
- Much work was spent on establishing a trustworthy bibliography. Well above planned estimates.
- That work continues.
- The results so far made will enter into, exploited in the upcoming **AMORE: Algorithmic Modelling of European Railways** project.
- Much work was spent on establishing a representative mailing list. Well above planned estimates.
- That work continues.
- Also this list will be used, exploited, in the **AMORE** project.
- Finally that project, **AMORE**, will require lead to a finer set of evaluations and comparisons than presented here.

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