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INNOTRACK

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Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D1.4.3 - Process for the linking of modelling tools

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Glossary

Abbreviation/acronym	Description
LCC	Life Cycle Costing
XML	eXtensible Markup Language
CSV	Comma Separated Variable
RAILMIL	Railway Mark-up Language
TCMS	Train Control and Management System
HTML	Hyper Text Markup Language
VTISM	Vehicle Track Interaction Strategic Model
B-2-B	Business to Business

Executive Summary

The assessment and reduction of Life Cycle Cost (LCC) in the railway domain depends on a number of component characteristics. One of the key features of any design of rolling stock or infrastructure component is the effect that it has on the LCC of the system. In the area of design and development there are many software tools that are implemented by the engineers and designers to asses these effects. In general these tools were developed independently of each other and, while some of them contain common features and concepts, they are named and represented in different ways.

The work outlined in this deliverable proposes a method for integrating different tools where the output of one tool could provide the input to another tool. In principle, any exchange of data between geographically remote systems and applications would use current Web standards for information interchange. This deliverable outlines a demonstration of the required Web standards and illustrates by example how this standard can be used to represent railway modelling data.

1. Introduction

Assessing the life cycle cost benefit of innovation requires the determination of influences that the change will have on the operational life of all the track components, the change in maintenance requirements and track availability. There is a requirement to quantify the effect of a change aimed at improving reliability, and to assess the impact that this change has over other components. It is equally desirable to compare the affects of proposed changes in different countries, e.g. comparing the effect of track degradation on vehicles in Austria with degradation in the UK.

There are a number of tools available that support the analysis of component design and the alteration of these designs. Document D1.3.2 – "The state of the art of the simulation of vehicle track interaction as a method for determining track degradation rates" introduces a number of these tools. IT describes in details the available features of some of them. To get the most benefit out of these tools it is beneficial in some cases to exchange data between them. For example, it might be necessary to feed the output of a track modelling package to the input of a vehicle simulator, providing the type of track profile that the vehicle will operate over. Alternatively, it would be appropriate to pass the output of vehicle design analysis to applications that asses the degradation of track parameters.

The transfer of data between two or more tools is currently performed manually. This procedure is time consuming and prone to error as the user/operator must copy all values correctly into the receiving system. A more convenient approach would be to link the tools through some network mechanism and exchange the data automatically.

Enabling a tool to exchange information with another tool requires a number of prerequisites to be assessed. For example the key issue is to establish if the tools in question already have some interface available to another system. Typically a number of questions need to be addressed, such as what operating system the application operates on, whether the system can be networked and what platform the system was developed on. In principle, any exchange of data between geographically remote systems and applications would rely on current available Web standards for information interchange. The most desirable approach would be the implementation of a standard for interchange that systems, that producing data of similar type, would subscribe to. However, in most cases the structure of data produced by a system is specific to the applications of that system. In many cases, it is in the system vendor's interest to create proprietary formats for data as it creates a dependency from the customer, i.e. any changes required in the output need to be addressed in the proprietary format and therefore generate work and revenue for the vendor. However, in the case of a standard protocol, there is an incentive to the vendor since they can subscribe to an open architecture by complying with a standard provided by the user.

The sections of this deliverable outline the study into Internet interchange standards highlighting by example how railway data could be expressed. It provides an outline of a XML data for Internet based data exchange and an example of railway specific data for exchange between modelling tools.

2. Use Case for Tool Interoperability in INNOTRACK

The Internet and related standards for information interchange have created a backbone for enterprise level information integration for large scale industries. The underlying technology is a mark up language from the same family as HTML called XML. XML is to data exchange and representation what HTML is to web page content exchange and representation. For the INNOTRACK tool requirements, there is likely to be a host of tools that could exchange information in an environment where modelling data us routinely integrated in the design process. The objective here is to define a scenario where data is likely to be exchanged leading to a demonstration of how it could be exchanged using the Internet technology.

The simplest example of a case for tool integration is one where there is a requirement for a vehicle manufacturer to alter the design of a vehicle. Providing the design change has some impact on the dynamics of the vehicle, it also likely to have an impact on the dynamic relationship with the track. Therefore the designer will want to test two characteristics: the affect of design on the vehicle dynamics and the effect of the design on the track. The designer may want to compare the output of different tools with the same vehicle model and analyse the impact of each on the same track modelling tool. To illustrate the case for standardisation of tool data representation we consider three vehicle modelling tools, Vampire (http://www.vampire-dynamics.com/index.html), Gensys (http://www.gensys.se/index.html) and NuCars (http://www.aar.com/nucars/about.asp). In principle these tools process the same data and produce the same results with some variation. However the important issue is that the characteristic input and output from each tool is unique to that tool and different from the other tools. We propose that the user would like to provide the output of these tools to some vehicle track interaction model such as VTISM. Figure 1 illustrates the current use case for this system level interaction.

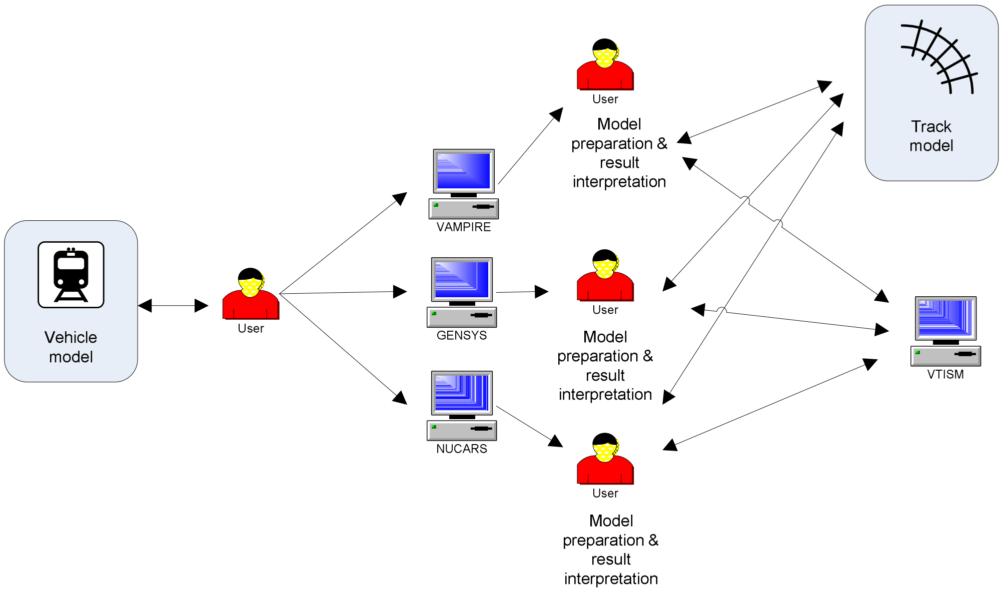

Figure 1 - Current use case for system interactions

Essentially the process defined here is manual and requires constant intervention by the user. Figure 2 illustrates the integrated approach where a controlling application supplies the output from the vehicle tools to the track analysis tool and displays the output to the user.

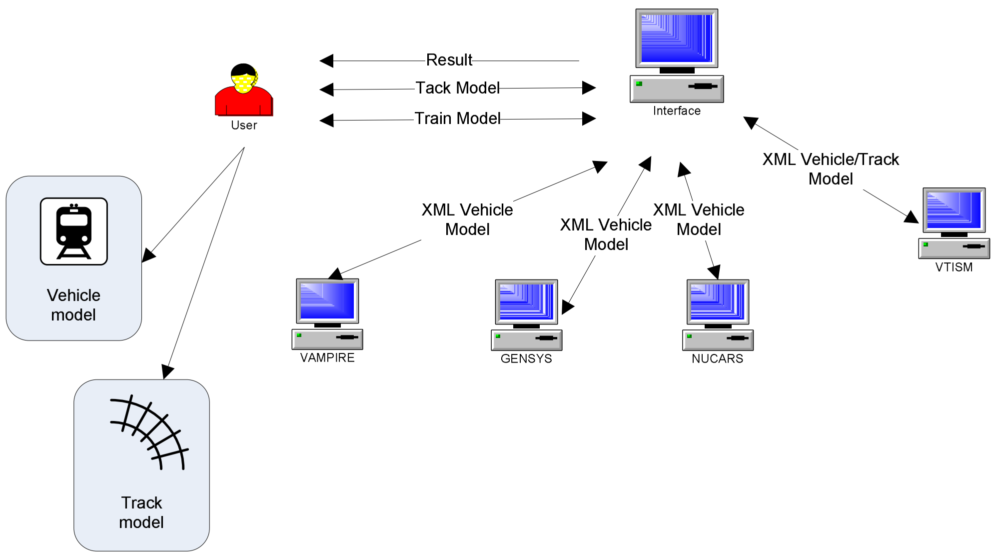

Figure 2 - Use case for tools with XML interface for integration

The benefit of this approach is that the interaction with the tools is transparent to the user and the result is displayed in common way for common tools and one interface.

Extending this case the train designer may want to compare the effect of the design in more than one context. For example, they may want to compare the performance of the vehicle in one country against another country. In this case is would be necessary to input the characteristics of a measured section of track from each country in conjunction with the vehicle model. The remainder of this document describes some background to how XML is used and created. It provides a example of a vehicle dynamic model in XML along with a representation of track geometry data.

3. Internet Technology

3.1 Background

The eXtensible Markup Language (XML) provides a standard way of representing data from an application. XML and related standards have become the key implementation technology for information transport over the World Wide Web [ref XML standard]. It has been used in a wide variety of applications ranging from Business to Business transactions (B-2-B), where transactional data is shared between financial applications to industrial information systems integration, where data about various industrial assets is integrated and processed [HS00], [LT01].

Essentially, XML uses a meta-level 'Schema' document which provides some restriction and control of what type, sequence and location of data that is allowed in an XML document. XML data is represented in a simple tree structure where each document has a *root element* from which all other elements branch…

```
<root>
 <child>
  <subchild>.....</subchild>
 </child>
</root>
```

Each component of the schema represents a "tag" that encapsulates a piece of data in the XML document. This means that the receiving application can reference the Schema document to establish what the restrictions are on the elements of the XML document. If all of the restrictions are met then the documents is deemed to be valid. An XML document representing data from a book store might look something like…

```
<bookstore>
<book category="COOKING">
 <title lang="en">Everyday Italian</title>
 <author>Giada De Laurentiis</author>
 <year>2005</year>
 <price>30.00</price>
</book>
<book category="CHILDREN">
 <title lang="en">Harry Potter</title>
 <author>J K. Rowling</author>
 <year>2005</year>
 <price>29.99</price>
</book>
<book category="WEB">
 <title lang="en">Learning XML</title>
 <author>Erik T. Ray</author>
 <year>2003</year>
 <price>39.95</price>
</book>
</bookstore>
```

In this document the <bookstore> element forms the *root element* and the <book> element forms the first branch of the tree. The <book> element has 4 children: <title>,< author>, <year>, <price> see http://www.w3schools.com/XML/xml_tree.asp for further information.

Using this approach, two applications (on independent systems) can communicate some piece of information, usually over the internet, and process it using the shared Schema.

In the railway domain considerable effort has been made to take advantage of the opportunities created by XML. For example, the work undertaken by Nash and Huerlimann in the RailML (Rail Mark-up Langauge) project, made some headway in the direction of creating a standard for information interchange in the railway domain [NH04]. RailML was intended as an open source data structure to simplify the transfer of data between various railway computer programs.

The motivation for this work was based on the requirement to efficiently use several different applications for planning improvements. To achieve this, data must be exported from one system and imported into another for further processing. This could be achieved by copying data from one system into the other, but this is a long and tedious process with a high risk of error. The preference is instead for this to be achieved by automatic data transfer which is transparent to the user. This can be achieved by creating a specialised interface for each application, but each time a new application is added, another interface is required. As the number of applications increases, so the number of possible data transfers increases significantly.

The requirements for the life cycle costing problems represent a similar situation. There are many systems that create and use data about identical or similar assets but that data is not available to a common tool without some common standard for interfacing them. Therefore, the ideal solution is one where system vendors agree to abide by some common data standard represented in XML. The proposed approach would be based on some study of both systems to ascertain data elements that are common to both and indeed those that are not. In the case where there are some differences in elements, these elements can be set as optional in the schema. This approach allows systems that do not provide, or can handle, these data elements to simply ignore them.

3.2 Interoperability with XML

XML data models provide a method representing syntactic data for information interchange across networks such as the Internet. While XML provides an opportunity for interoperability between information systems, it does have limitations because it only provides and interchange format. The semantics of the information stored in XML documents is open to interpretation and misinterpretation. XML can support the storage of a minimal amount of semantics within the schema document. But these semantics are limited to the sequence occurrences of data and the nesting structure of that data. Therefore, it is noted that automatic interchange between tools requires some careful design of the interface that send, receives and processes XML data.

3.3 Producing XML Data

XML data is easy to create using modern programming environments. For example, Microsoft .NET (which cover languages such as C/C++ and C#) provides a suite of Application Programming Interfaces (APIs), which are pre-written applications, for creating and processing XML data. To demonstrate the ease of use we represent a sample of Train TCMS data in a standards notation (CSV) - see appendix A.

The following C# code excerpt illustrates the simplicity of programmatically producing an XML document based on this data. The 'resultArray' holds the array of data copied from the source file in Appendix A.

```
String[] resultArray = new string[100];

XmlDocument xmlDoc = new XmlDocument();
XmlTextWriter testTextWriter = new
XmlTextWriter(XMLFilename, null);
testTextWriter.Formatting = Formatting.Indented;
testTextWriter.WriteStartDocument(true);
testTextWriter.WriteDocType("TCMS_DATA", null, null, null);
testTextWriter.WriteStartElement("root");
```

```
        testTextWriter.WriteElementString("HEADER", "Text");
        testTextWriter.WriteStartElement("BODY", null);
        testTextWriter.WriteStartElement("TRAIN_TCMS", null);
        testTextWriter.WriteAttributeString("UNIT_NUMBER", resultArray[2].ToString());
        testTextWriter.WriteAttributeString("CAR_NUMBER", resultArray[3].ToString());
        testTextWriter.WriteStartElement("FAULT", null);
        testTextWriter.WriteAttributeString("FAULT_NUM", resultArray[9].ToString());
testTextWriter.WriteAttributeString("DESCRIPTION", resultArray[4].ToString());
testTextWriter.WriteAttributeString("dateTime",   resultArray[0].ToString()   +   "T"   +
resultArray[1].ToString());
testTextWriter.WriteAttributeString("CATEGORY", resultArray[5].ToString());
          testTextWriter.WriteAttributeString("FUNCTION", resultArray[6].ToString());
testTextWriter.WriteEndElement();
testTextWriter.WriteEndElement();
testTextWriter.WriteEndElement();//Body
testTextWriter.WriteEndElement();//Root
testTextWriter.Flush();
testTextWriter.Close();
```

The result of running this simple code is an XML document…

```
<?xml version="1.0" standalone="yes"?>
<!DOCTYPE TCMS_DATA>
<root>
 <HEADER>Text</HEADER>
 <BODY>
  <TRAIN_TCMS UNIT_NUMBER="TrainConsist_001" CAR_NUMBER="1">
   <FAULT   FAULT_NUM="3296"   DESCRIPTION="TNM   Successful   Reset   –   Car   DAC"
dateTime="02/01/07T00:35:36"    CATEGORY="Maintenance    Fault"    FUNCTION="Train
Management System" />
  </TRAIN_TCMS>
 </BODY>
</root>
```

This simple example helps to visualise how a number of independent applications could share this data. For the life cycle costing case, a similar approach could be applied where a generic schema is produced. It should be noted that the portability of course is not restricted to applications coded in C# or using the .NET framework.

4. Train Model Case Study

Background

To demonstrate the requirements to link tools using XML, we consider a number of different applications that enables the user to build a dynamic model of a rail vehicle. These dynamic models are used to study the response to real measured track geometry or user specified inputs in the form of track displacements and external force inputs. These systems are Vampire (http://www.vampire-dynamics.com/index.html), Gensys (http://www.gensys.se/index.html) and NuCars (http://www.aar.com/nucars/about.asp). In general they perform identical functions using similar data represented in different formats [SI08].

In this case study, we consider the requirement to compare the results from all applications of this type. In this case it is desirable to create one dynamic model of the vehicle and employ it in all three of the tools. To demonstrate this we consider the Vampire vehicle specification - Appendix B, in section 5 Annexes, describes the specification for the vehicle model in Vampire and Appendix C provides an example vehicle model used.

The equivalent of this model in XML is an XML schema that describes the specification and an XML document that provides an instance of a vehicle model.

4.1 XML Schema and Data

The example XML model is built on a number of assumptions. First, that each file represents an individual vehicle and second, that each vehicle consists of at least two and not more than two bogies. It can be seen that XML is ideal for representing this type of information for two reasons: first, the restriction can be captured in the schema so that it can be observed by the user and second the restriction can be used to check if the XML data is valid with respect to the schema.

```
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSPY v5 rel. 3 U (http://www.xmlspy.com) -->
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema" elementFormDefault="qualified"
attributeFormDefault="unqualified">
    <xs:element name="VEHICLEMODEL">
        <xs:annotation>
            <xs:documentation>Piecewise linear vehicle model</xs:documentation>
        </xs:annotation>
        <xs:complexType>
            <xs:sequence>
                <xs:element name="BOGIE" minOccurs="2" maxOccurs="2">
                    <xs:complexType>
                        <xs:choice>
                            <xs:element name="SUSPENSION_CHARACTERISTICS">
                                <xs:complexType>
                                    <xs:sequence>
                                        <xs:element name="TRAILING_ARM_BUSH" maxOccurs="4">
                                            <xs:complexType>
                                                <xs:sequence>
                                                    <xs:element name="LONGITUDINAL_STIFFNESS" type="xs:decimal">
                                                        <xs:annotation>
                                                            <xs:documentation>Units: kN/m</xs:documentation>
                                                        </xs:annotation>
                                                </xs:element>
```

The complete XML schema for this model can be found in Appendix D of section 5. A graphical representation of the schema is shown in Figure 3.

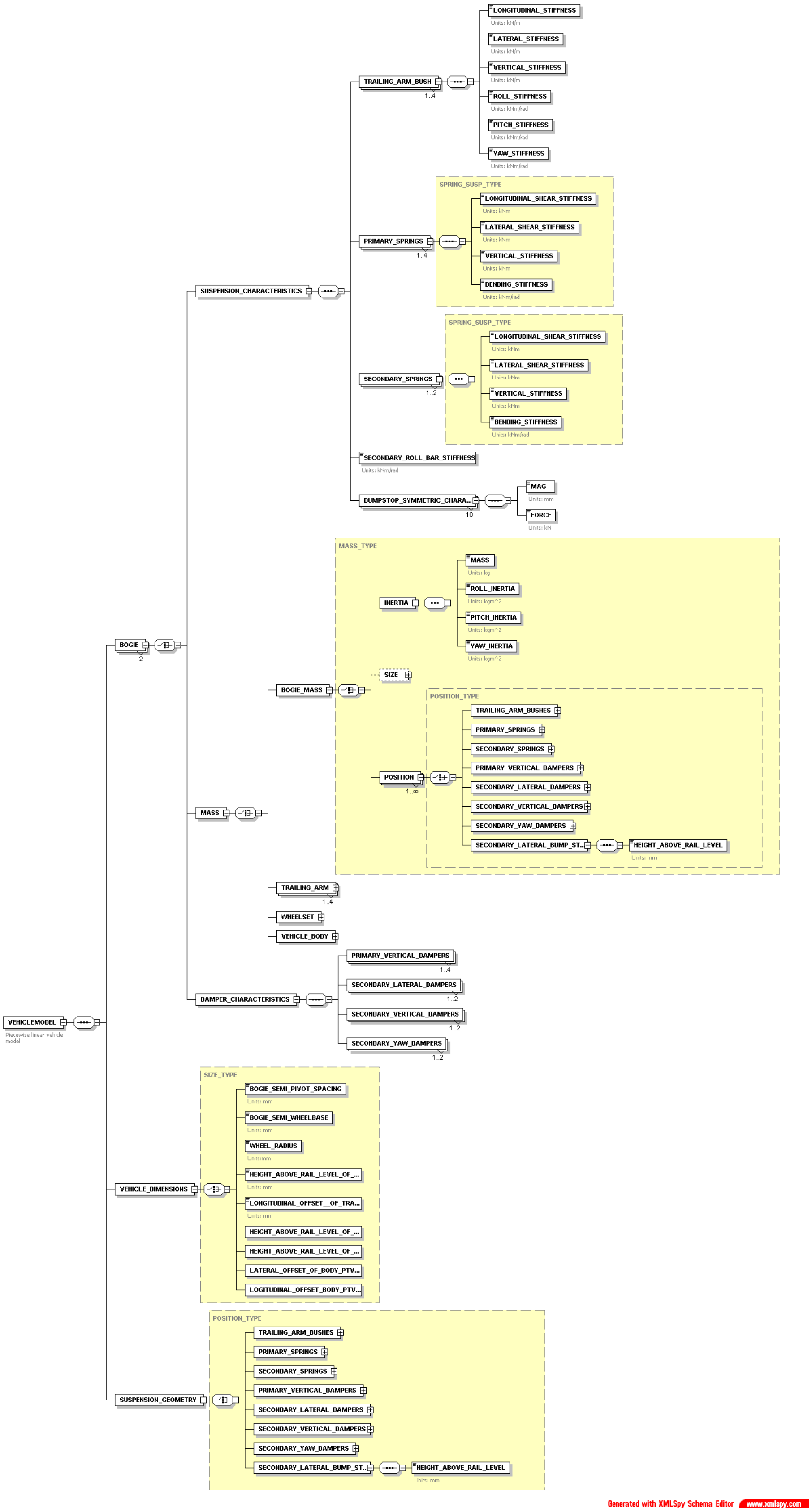

Figure 3 - Graphical representation of XML schema for vehicle model

Using this schema a vehicle model can be constructed that all of the vehicle modelling tools could potentially accept as input. The vehicle data is created as an XML file that matches the schema. An example of this data file is shown below – note that the data has been generated by an editor so the values are not true data values for the model.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<!--Sample XML file generated by XMLSPY v5 rel. 3 U (http://www.xmlspy.com)-->
<VEHICLEMODEL xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="C:\MAINDRIVE\INNOTRACK Files\VehicleModel_1.xsd" model_ID="String">
    <BOGIE bogie_num="1">
        <SUSPENSION_CHARACTERISTICS>
            <TRAILING_ARM_BUSH>
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            <LATERAL_SEMI_SPACING>3.14159265358979323846264338327950</LATERAL_SEMI_SPACING>
        </TRAILING_ARM_BUSHES>
    </SUSPENSION_GEOMETRY>
</VEHICLEMODEL>
```


4.2 Track Geometry Data

Since the train modelling applications also require track geometry data in order to study the behaviour of train models, it is also desirable for similar models to exist. Figure 3 shows and sample of UGMS track geometry data along with a table describing the features that can be measured. This sample illustrates that an appropriate XML schema representation of this data could easily be produced.

ELR	Track Code	Location miles,yards	Location GPS coordinates	Date	Time	Fault Magnitude	Fault Type
ECM1	3200	155m1402y	53.51962:-1.14001	02/11/2006	13:34:16	-21.15	T35R
ECM1	3200	155m1387y	53.51949:-1.14001	02/11/2006	13:34:19	-19.51	TW3M
ECM1	3200	155m1379y	53.51944:-1.14001	02/11/2006	13:34:19	16.24	AL35
ECM1	3200	155m1365y	53.51933:-1.14001	02/11/2006	13:34:21	-16.52	AL35
ECM1	3200	155m1354y	53.51925:-1.14003	02/11/2006	13:34:22	21.01	AL35
ECM1	3718	155m1240y	53.51829:-1.14015	02/11/2006	13:34:34	-33.01	AL35
PED5	2100	155m1228y	53.51815:-1.14020	02/11/2006	13:34:36	59.62	AL35
PED5	2100	022m1152y	53.51793:-1.14028	02/11/2006	13:34:38	-63.67	AL35
PED5	2100	022m1125y	53.51768:-1.14037	02/11/2006	13:34:42	55.63	AL35
PED5	2100	022m1110y	53.51758:-1.14042	02/11/2006	13:34:44	-37.6	AL35
SJM2	2100	015m0733y	53.49280:-1.29895	02/11/2006	13:43:25	-39.41	T35L
SJM2	2100	015m0733y	53.49280:-1.29895	02/11/2006	13:43:25	-38.95	T35R
SJM2	2100	015m0727y	53.49283:-1.29913	02/11/2006	13:43:30	41.04	T35L
SJM2	2100	015m0727y	53.49283:-1.29913	02/11/2006	13:43:30	40.75	T35R
TJC3	1100	165m1084y	53.46732:-1.31053	02/11/2006	13:46:51	16.87	TW3M
TJC3	1100	165m0425y	53.46291:-1.31599	02/11/2006	13:48:19	-37.13	T35L

ELR			Route
TID			Track ID
Section	from		Section from
Section	to		Section to
GPS SD			Date
GPS ST			Time
T35L	mm	sd	Top 35m L
T35L	n	MC1	Top 35m L
T35R	mm	sd	Top 35m R
T35R	n	MC1	Top 35m R
A35L	mm	sd	Alignment 35m L
A35L	n	MC1	Alignment 35m L
A35R	mm	sd	Alignment 35m R

A35R	n	MC1	Alignment 35m R
AL35	mm	sd	Mean alignment 35
AL35	n	MC1	Mean alignment 35
MT70	mm	sd	Mean Top 70
MT70	n	MC1	Mean Top 70
AL70	mm	sd	Mean alignment 70
AL70	n	MC1	Mean alignment 70
MT120		sd	Mean Top 120
MT120	n	MC1	Mean Top 120
AL120		sd	Mean alignment 120
AL120	n	MC1	Mean alignment 120
GAUG	mm	Mn.01	Gauge
GAUG	n	MC1	Gauge
TW3M	mm	sd	Twist 3m
TW3M	n	MC1	Twist 3m
TW5M	mm	sd	Twist 5m
TW5M	n	MC1	Twist 5m

MC1	Count of threshold Level 1 exceedances
sd	Standard deviation

5. Conclusion

The work outlined in this deliverable proposes a method for integrating different tools that are implemented by the engineers and designers in assessing changes in design and the associated effects on LCC. In the case where the output of one tool could be provided as the input to another tool, it is feasible for this interoperation to be performed automatically. It is believed that the interoperation of these tools could support the case for reduction of LCC in railways.

The transfer of data between two or more tools is currently performed manually. This procedure is time consuming and prone to error as the user/operator must copy all values correctly into the receiving system. A more convenient approach would be to link the tools through some network mechanism and exchange the data automatically. This interoperation is demonstrated through the implementation of Web standards and illustrates by example how this standard can be used to represent railway modelling data. The sections of this deliverable outline the study into Internet interchange standards highlighting by example how railway data could be expressed. It provides an outline of a XML data for Internet exchange and an example of railway specific data models providing as example for exchange between modelling tools.

The solution proposed in this deliverable is applicable to many areas of INNOTRACK and not restricted to the interoperation of tools. The current status of this work covers a simple example of interoperability between a number of well known applications and the appropriate XML models have been produced. The result of this investigation is extendable within INNOTRACK, leading to a standardised set of XML models to improve the interoperability between software.

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7. Annexes

7.1 Appendix A – Sample Train TCMS fault data

```
Date          Time          Unit Number         Car No Fault Desc
         Category  Function
02/01/2007   00:35:36     TrainConsist_001    1      TNM  Successful  Reset  -  Car  DAC
      Maintenance Fault   Train Management System
Recorded by  SW Ref Fault No
TMCC1  F1_TMTERMSR  3296
```

7.2 Appendix B – Example Vehicle Specification

Masses & Inertias

Wheelset:		
Mass (including part of bearings)	1503	kg
Roll inertia	810	kgm^2
Pitch inertia	112	kgm^2
Yaw inertia	810	kgm^2
Trailing Arm: (x4 per bogie)		
Mass (including part of bearings, springs & dampers)	155	kg
Roll inertia	2.10	kgm^2
Pitch inertia	5.60	kgm^2
Yaw inertia	5.60	kgm^2
Bogie:		
Mass (including part of bearings, springs & dampers)	2615	kg
Roll inertia	1722	kgm^2
Pitch inertia	1476	kgm^2
Yaw inertia	3067	kgm^2
Body:		
Mass (including part of bearings, springs & dampers)	32000	kg
Roll inertia	56800	kgm^2
Pitch inertia	1970000	kgm^2
Yaw inertia	1970000	kgm^2

Suspension Characteristics

Trailing Arm Bush: (x4 per bogie)		
Longitudinal stiffness	30774	kN/m
Lateral stiffness	3267	kN/m
Vertical stiffness	50000	kN/m
Roll stiffness	20	kNm/rad
Pitch stiffness	10	kNm/rad
Yaw stiffness	20000	kNm/rad
Primary springs: (x4 per bogie)		
Longitudinal shear stiffness	617	kN/m
Lateral shear stiffness	617	kN/m
Vertical stiffness	732	kN/m
Bending stiffness	7.28	kNm/rad
Secondary Springs: (x2 per bogie)		
Longitudinal shear stiffness	160	kN/m
Lateral shear stiffness	160	kN/m
Vertical stiffness	430	kN/m
Bending stiffness	10.50	kNm/rad
Secondary roll bar stiffness (x1 per bogie)	940	kNm/rad

Secondary lateral bumpstop: (x1 per bogie)
Symmetric characteristic

0	25	30	35	40	45	50	55	60	65	mm
0	0	0.60	1.76	3.73	6.87	11.58	17.17	29.20	230	kN

Damper Characteristics

Primary vertical dampers: (x4 per bogie)
Symmetric characteristic

0	0.04	0.09	0.16	0.28	1.00	10.0	20.0	50.0	m/s
0	0.1	0.2	0.3	0.4	1.0	8.5	16.8	42.0	kN
Series stiffness							600	kN/m	

Secondary lateral dampers: (x2 per bogie)
Symmetric characteristic

0	0.03	0.07	0.15	0.305	1.0	10.0	20.0	m/s
0	1.0	2.0	3.0	4.0	8.5	66.5	131.0	kN
Series stiffness							6000	kN/m

Secondary vertical dampers: (x2 per bogie)
Symmetric characteristic

0	0.0015	0.08	0.26	1.0	10.0	20.0	m/s
0	1.0	2.0	3.0	7.1	57.1	112.6	kN
Series stiffness							6000 kN/m

Secondary yaw dampers: (x2 per bogie)
Symmetric characteristic

0	0.04	0.055	0.11	0.14	1.0	10.0	20.0	m/s
0	7.0	8.0	10.0	11.0	39.7	339.7	673.3	kN
Series stiffness							30000	kN/m

Vehicle Dimensions

Bogie semi pivot spacing	9500	mm
Bogie semi wheelbase	1280	mm
Wheel radius	460	mm
Height above rail level of training arm cofg	490	mm
Longitudinal offset of trailing armn cofg from bogie centre	1200	mm
Height above rail level of bogie cofg	600	mm
Height above rail level of body cofg	1800	mm
Lateral offset of body cofg from body centre (positive to right)	50	mm
Longitudinal offset body cofg from body centre (positive forward)	200	mm

Suspension Geometry (please refer to diagram at end of notes)

Trailing arm bushes:			
Longitudinal semi spacing	(x1)	830	mm
Lateral semi spacing	(y1)	1000	mm
Height above rail level	(h1)	460	mm
Primary springs:			
Longitudinal semi spacing	(x2)	1280	mm
Lateral semi spacing	(y2)	1000	mm
Height above rail level of top	(h2)	940	mm
Height above rail level of bottom	(h3)	680	mm
Secondary springs:			
Lateral semi spacing	(y3)	1000	mm
Height above rail level of top	(h4)	1130	mm
Height above rail level of bottom	(h5)	525	mm

Primary vertical dampers:			
Longitudinal semi spacing	(x3)	1550	mm
Lateral semi spacing	(y4)	1000	mm
Height above rail level of top	(h6)	880	mm
Height above rail level of bottom	(h7)	480	mm
Secondary lateral dampers:			
Lateral semi spacing of bolster end	(y5)	665	mm
Lateral semi spacing of bogie end	(y6)	230	mm
Height above rail level of bolster end	(h8)	750	mm
Height above rail level of bogie	(h9)	650	mm
Secondary vertical dampers:			
Lateral semi spacing of top	(y7)	1335	mm
Lateral semi spacing of bottom	(y8)	1300	mm
Height above rail level of top	(h10)	925	mm
Height above rail level of bottom	(h11)	400	mm
Secondary yaw dampers:			
Longitudinal offset body end from bogie centre	(x6)	1106	mm
Longitudinal offset bogie end from bogie centre	(x7)	230	mm
Lateral semi spacing	(y9)	1410	mm
Height above rail level of body end	(h12)	630	mm
Height above rail level of bogie end	(h13)	525	mm
Secondary lateral bumpstop:			
Height above rail level	(h14)	650	mm

7.3 Appendix C – Example Vampire Vehicle Model

```
Worked Example Vehicle Model (ERRI B176 Benchmark Vehicle)
**
**  VEHICLE FILE CONVERTED TO v4.00 FORMAT  **
**
     UNITS  Standard
**
*MASS
** Vehicle body with offset centre of gravity
     INERTIA   32.0 56.8 1970.0 1970.0            tonnes
     POSITION  0.2 0.05 1.8
     SIZE    -12.0 -1.60 0.75 12.00 1.60 3.60
** Bogies
     INERTIA  2.615 1.722 1.476 3.067
     POSITION  9.5 0.0 0.6
     SIZE     7.2 -1.20 0.50 11.80 1.20 1.10
     POSITION  -9.5 0.0 0.6
     SIZE    -11.8 -1.20 0.50 -7.20 1.20 1.10
*WHEELSET
** Wheelsets (including mass and inertia of axleboxes)
     INERTIA  1.813 1.12 0.0056
     POSITION  10.78 0.0 0.46
     POSITION  8.22 0.0 0.46
     POSITION  -8.22 0.0 0.46
     POSITION  -10.78 0.0 0.46
*STIFFNESS
** Longitudinal stiffness to ground
     STIFFNESS 0.01
     POSITION  0.10     0.0    1.80    1
          -0.10     0.0    1.80    0
*SHEAR
** Secondary springs
** - Leading bogie
     STIFFNESS 0.160  0.160  0.430  0.0105  0.0105  0.0
     POSITION      9.5    1.0   1.130    0.525   1   2
     POSITION      9.5   -1.0   1.130    0.525   1   2
** - Trailing bogie
     POSITION     -9.5    1.0   1.130    0.525   1   3
     POSITION     -9.5   -1.0   1.130    0.525   1   3
** Primary springs
** - Leading bogie
     STIFFNESS 0.617  0.617  0.732  0.00728  0.00728  0.0
     POSITION     10.78    1.0   0.940    0.680   2   4
     POSITION     10.78   -1.0   0.940    0.680   2   4
     POSITION      8.22    1.0   0.940    0.680   2   5
     POSITION      8.22   -1.0   0.940    0.680   2   5
** - Trailing bogie
     POSITION     -8.22    1.0   0.940    0.680   3   6
     POSITION     -8.22   -1.0   0.940    0.680   3   6
     POSITION    -10.78    1.0   0.940    0.680   3   7
     POSITION    -10.78   -1.0   0.940    0.680   3   7
*BUSH
** Trailing arm bushes
** - Leading bogie
     STIFFNESS 30.774  3.267  50.0  0.020  0.010  20.0
     DAMPING   0.015  0.005  0.02  0.0  0.0  0.0
     SERIES    60.0  6.5  100.0  0.0  0.0  0.0
```

....

```
        STATIC NONE
        POSITION  10.33 1.0 0.46 2 4
        POSITION  10.33 -1.0 0.46 2 4
        POSITION  8.67 1.0 0.46 2 5
        POSITION  8.67 -1.0 0.46 2 5
** - Trailing bogie
        POSITION  -8.67 1.0 0.46 3 6
        POSITION  -8.67 -1.0 0.46 3 6
        POSITION  -10.33 1.0 0.46 3 7
        POSITION  -10.33 -1.0 0.46 3 7
** Secondary traction and roll bars
        STIFFNESS 5.0 0.0 0.0 0.940 0.0 0.0
        DAMPING   0.025 0.0 0.0 0.0 0.0 0.0
        SERIES    10.0 0.0 0.0 0.0 0.0 0.0
        POSITION  9.50 0.0 0.60 1 2
        POSITION  -9.50 0.0 0.60 1 3
*DAMPER
** Primary vertical dampers
** - Leading bogie
        VELOCITY  0.04 0.09 0.16 0.28 20.0 50.0
        FORCE     0.1 0.2 0.3 0.4 16.8 42.0
        SERIES    0.6
        POSITION  11.05   1.0   0.88   2
                  11.05   1.0   0.48   4
        POSITION  11.05   -1.0  0.88   2
                  11.05   -1.0  0.48   4
        POSITION  7.95    1.0   0.88   2
                  7.95    1.0   0.48   5
        POSITION  7.95    -1.0  0.88   2
                  7.95    -1.0  0.48   5
** - Trailing bogie
        POSITION  -7.95   1.0   0.88   3
                  -7.95   1.0   0.48   6
        POSITION  -7.95   -1.0  0.88   3
                  -7.95   -1.0  0.48   6
        POSITION  -11.05  1.0   0.88   3
                  -11.05  1.0   0.48   7
        POSITION  -11.05  -1.0  0.88   3
                  -11.05  -1.0  0.48   7
** Secondary vertical dampers
** - Leading bogie
        VELOCITY  0.015 0.08 0.26 1.0 10.0 20.0
        FORCE     1.0 2.0 3.0 7.1 57.1 112.6
        SERIES    6.0
        POSITION   9.5  1.335   0.925   1
                   9.5  1.30    0.40   2
        POSITION   9.5  -1.335  0.925   1
                   9.5  -1.30   0.40   2
** - Trailing bogie
        POSITION   -9.5  1.335  0.925   1
                   -9.5  1.30   0.40   3
        POSITION   -9.5  -1.335  0.925   1
                   -9.5  -1.30  0.40   3
** Secondary lateral dampers
** - Leading bogie
        VELOCITY  0.03 0.07 0.15 0.305 1.0 10.0
        FORCE     1.0 2.0 3.0 4.0 8.5 66.5
        SERIES    6.0
        POSITION   9.5  0.665   0.75   1
```

```
          9.5   0.230    0.65   2
     POSITION    9.5  -0.665    0.75   1
          9.5  -0.230    0.65   2
** - Trailing bogie
     POSITION   -9.5   0.665    0.75   1
          -9.5   0.230    0.65   3
     POSITION   -9.5  -0.665    0.75   1
          -9.5  -0.230    0.65   3
** Secondary yaw dampers
** - Leading bogie
     VELOCITY  0.04 0.055 0.11 0.14 1.0 10.0
     FORCE     7.0 8.0 10.0 11.0 39.7 339.7
     SERIES    30.0
     POSITION  8.394   1.410    0.63   1
          9.270   1.410   0.525   2
     POSITION  8.394  -1.410    0.63   1
          9.270  -1.410   0.525   2
** - Trailing bogie
     POSITION -8.394   1.410    0.63   1
          -9.270   1.410   0.525   3
     POSITION -8.394  -1.410    0.63   1
          -9.270  -1.410   0.525   3
*BUMPSTOP
** Secondary Lateral
** - Leading bogie
     DISPLACE  -65.0 -60.0 -55.0 -50.0 -45.0 -40.0~
          -35.0 -30.0 -25.0 0.0 65.0
     FORCE     -230.0 -29.2 -17.17 -11.58 -6.87 -3.73~
          -1.76 -0.60 0.0 0.0 0.0
     POSITION    9.5  -0.1  0.65  2
          9.5  0.0  0.65  1
     POSITION    9.5   0.1  0.65  2
          9.5  0.0  0.65  1
** - Trailing bogie
     POSITION   -9.5  -0.1  0.65  3
          -9.5  0.0  0.65  1
     POSITION   -9.5   0.1  0.65  3
          -9.5  0.0  0.65  1
*
```

7.4 Appendix D – Vehicle Specification XML Schema

```
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSPY v5 rel. 3 U (http://www.xmlspy.com) by Richard Lewis (University of Birmingham) -->
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema" elementFormDefault="qualified"
attributeFormDefault="unqualified">
    <xs:element name="VEHICLEMODEL">
        <xs:annotation>
            <xs:documentation>Piecewise linear vehicle model</xs:documentation>
        </xs:annotation>
        <xs:complexType>
            <xs:sequence>
                <xs:element name="BOGIE" minOccurs="2" maxOccurs="2">
                    <xs:complexType>
                        <xs:choice>
                            <xs:element name="SUSPENSION_CHARACTERISTICS">
                                <xs:complexType>
                                    <xs:sequence>
                                        <xs:element name="TRAILING_ARM_BUSH" maxOccurs="4">
                                            <xs:complexType>
                                                <xs:sequence>
                                                    <xs:element name="LONGITUDINAL_STIFFNESS" type="xs:decimal">
                                                        <xs:annotation>
                                                            <xs:documentation>Units: kN/m</xs:documentation>
                                                        </xs:annotation>
                                                    </xs:element>
                                                    <xs:element name="LATERAL_STIFFNESS" type="xs:decimal">
                                                        <xs:annotation>
                                                            <xs:documentation>Units: kN/m</xs:documentation>
                                                        </xs:annotation>
                                                    </xs:element>
                                                    <xs:element name="VERTICAL_STIFFNESS" type="xs:decimal">
                                                        <xs:annotation>
                                                            <xs:documentation>Units: kN/m</xs:documentation>
                                                        </xs:annotation>
                                                    </xs:element>
                                                    <xs:element name="ROLL_STIFFNESS" type="xs:decimal">
                                                        <xs:annotation>
                                                            <xs:documentation>Units: kNm/rad</xs:documentation>
                                                        </xs:annotation>
                                                    </xs:element>
                                                    <xs:element name="PITCH_STIFFNESS" type="xs:decimal">
                                                        <xs:annotation>
                                                            <xs:documentation>Units: kNm/rad</xs:documentation>
                                                        </xs:annotation>
                                                    </xs:element>
                                                    <xs:element name="YAW_STIFFNESS" type="xs:decimal">
                                                        <xs:annotation>
                                                            <xs:documentation>Units: kNm/rad</xs:documentation>
                                                        </xs:annotation>
                                                    </xs:element>
                                                </xs:sequence>
                                            </xs:complexType>
                                        </xs:element>
                                        <xs:element name="PRIMARY_SPRINGS" type="SPRING_SUSP_TYPE"
maxOccurs="4"/>
                                        <xs:element name="SECONDARY_SPRINGS" type="SPRING_SUSP_TYPE"
maxOccurs="2"/>
                                        <xs:element name="SECONDARY_ROLL_BAR_STIFFNESS" type="xs:decimal">
                                            <xs:annotation>
                                                <xs:documentation>Units: kNm/rad</xs:documentation>
                                            </xs:annotation>
                                        </xs:element>
                                        <xs:element name="BUMPSTOP_SYMMETRIC_CHARACTERISTIC" minOccurs="10"
maxOccurs="10">
                                            <xs:complexType>
```

```
                                    <xs:sequence>
                                        <xs:element name="MAG" type="xs:int">
                                            <xs:annotation>
                                                <xs:documentation>Units: mm</xs:documentation>
                                            </xs:annotation>
                                        </xs:element>
                                        <xs:element name="FORCE" type="xs:decimal">
                                            <xs:annotation>
                                                <xs:documentation>Units: kN</xs:documentation>
                                            </xs:annotation>
                                        </xs:element>
                                    </xs:sequence>
                                </xs:complexType>
                            </xs:element>
                        </xs:sequence>
                    </xs:complexType>
                </xs:element>
                <xs:element name="MASS">
                    <xs:complexType>
                        <xs:choice>
                            <xs:element name="BOGIE_MASS">
                                <xs:complexType>
                                    <xs:complexContent>
                                        <xs:extension base="MASS_TYPE"/>
                                    </xs:complexContent>
                                </xs:complexType>
                            </xs:element>
                            <xs:element name="TRAILING_ARM" type="MASS_TYPE" maxOccurs="4"/>
                            <xs:element name="WHEELSET" type="MASS_TYPE"/>
                            <xs:element name="VEHICLE_BODY" type="MASS_TYPE"/>
                        </xs:choice>
                    </xs:complexType>
                </xs:element>
                <xs:element name="DAMPER_CHARACTERISTICS">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="PRIMARY_VERTICAL_DAMPERS" maxOccurs="4"/>
                            <xs:element name="SECONDARY_LATERAL_DAMPERS" maxOccurs="2"/>
                            <xs:element name="SECONDARY_VERTICAL_DAMPERS" maxOccurs="2"/>
                            <xs:element name="SECONDARY_YAW_DAMPERS" maxOccurs="2"/>
                        </xs:sequence>
                    </xs:complexType>
                </xs:element>
            </xs:choice>
            <xs:attribute name="bogie_num" type="xs:int" use="required"/>
        </xs:complexType>
    </xs:element>
    <xs:element name="VEHICLE_DIMENSIONS" type="SIZE_TYPE"/>
    <xs:element name="SUSPENSION_GEOMETRY" type="POSITION_TYPE"/>
  </xs:sequence>
  <xs:attribute name="model_ID" type="xs:string" use="required"/>
 </xs:complexType>
</xs:element>
<xs:complexType name="MASS_TYPE">
    <xs:annotation>
        <xs:documentation>Mass and inertia of components</xs:documentation>
    </xs:annotation>
    <xs:choice>
        <xs:element name="INERTIA">
            <xs:complexType>
                <xs:sequence>
                    <xs:element name="MASS" type="xs:decimal">
                        <xs:annotation>
                            <xs:documentation>Units: kg</xs:documentation>
                        </xs:annotation>
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