CSHM-5, Ymaguchi Japan
Global Health Monitoring System of Bridges in Finland

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Global Health Monitoring System of Bridges in Finland, Contents

1. Introduction
2. Global management system of bridges
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Global Health Monitoring System of Bridges in Finland, Goal

- **Global Health Monitoring System of Bridges = GHMSB**

Goal

The main idea is **to combine the following subjects** and tasks into the global bridge monitoring and management system

- Bridge register and database
- Bridge monitoring system
- Bridge strength analyzing
- Bridge deterioration analyzing
- Bridge testing

1. GHMSB in Finland, Introduction

Finland

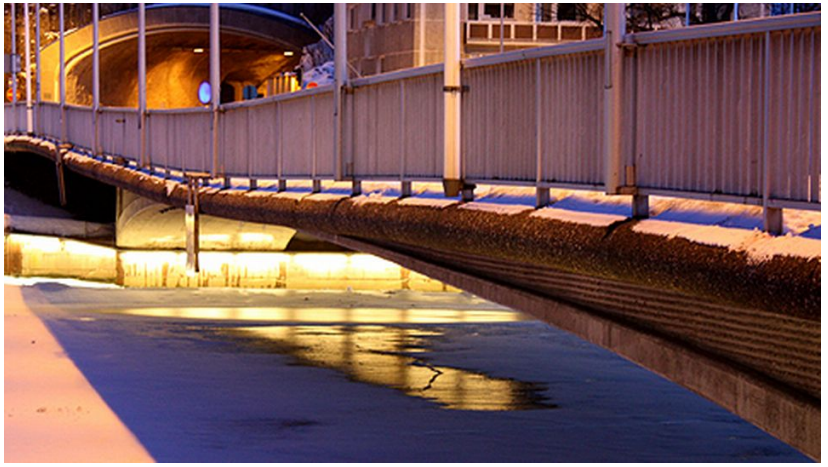
- Area 340 000 km^2
- Population of 5.4 millions
- 17.6 inhabitants/km^2
- 10 % of the total area is coved by the lakes and rivers

1. GHMSB in Finland, Introduction

Bridges in Finland

- 15 000 bridges
- Longest bridge span 250 m, length 1045 m (Raippaluoto suspension bridge)
- Most of the bridges are concrete bridges

- **200 bridges are in very bad condition and 800 bridges in bad condition**



1. GHMSB in Finland, Introduction

- Most of the bridges in Finland are **in bridge register**
- The register also includes bridges of some cities and towns
- The information model of basic parameters of bridges are in development phase
- The drawing of bridges have been microfilmed, but only the models of **newest bridges are in digital format**

- Load tests with heavy lorries and mobile cranes have been performed for about 100 bridges during 20 years (about from 3 to 5 bridges in a year)

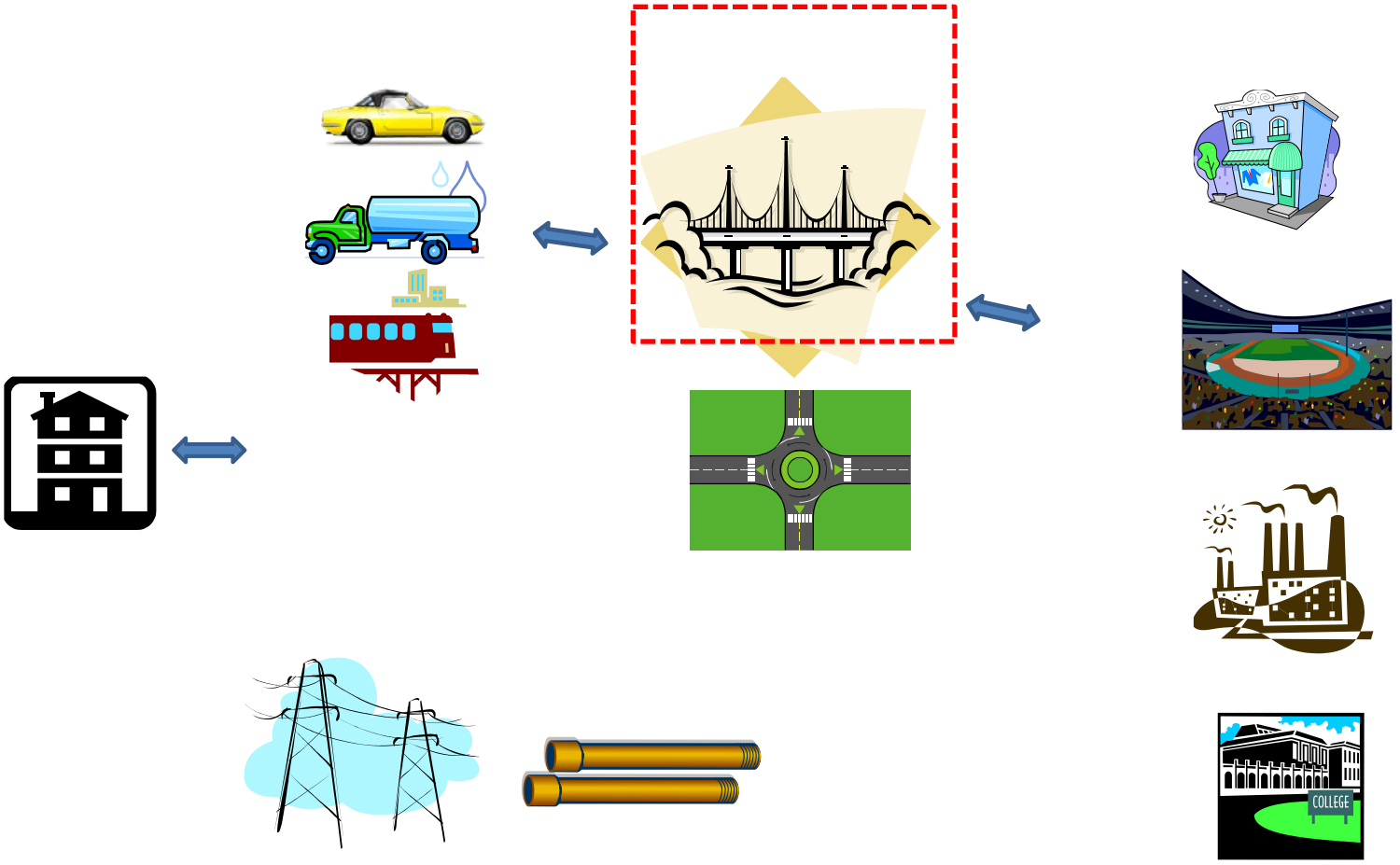
- Long term monitoring equipments have been installed for about 10 bridges

2. GHMSB, Global Management System of Bridges

- The global management system of bridges (GMSB) is part of the global management system of Infra (GMSI).
- The data and information needed for bridge is coming from common information of roads, traffic and travelling
- The global bridge management system is not only a database including geometrical and material information about the bridges, but **in the future it will also include the whole information model of bridges.**
- While building the GHMSB, we have to include the GHBSI. This means, that all the common data can be in the future available by other systems

2. GHMSB, Global Management System of Bridges

- Bridges belong to the infra structures



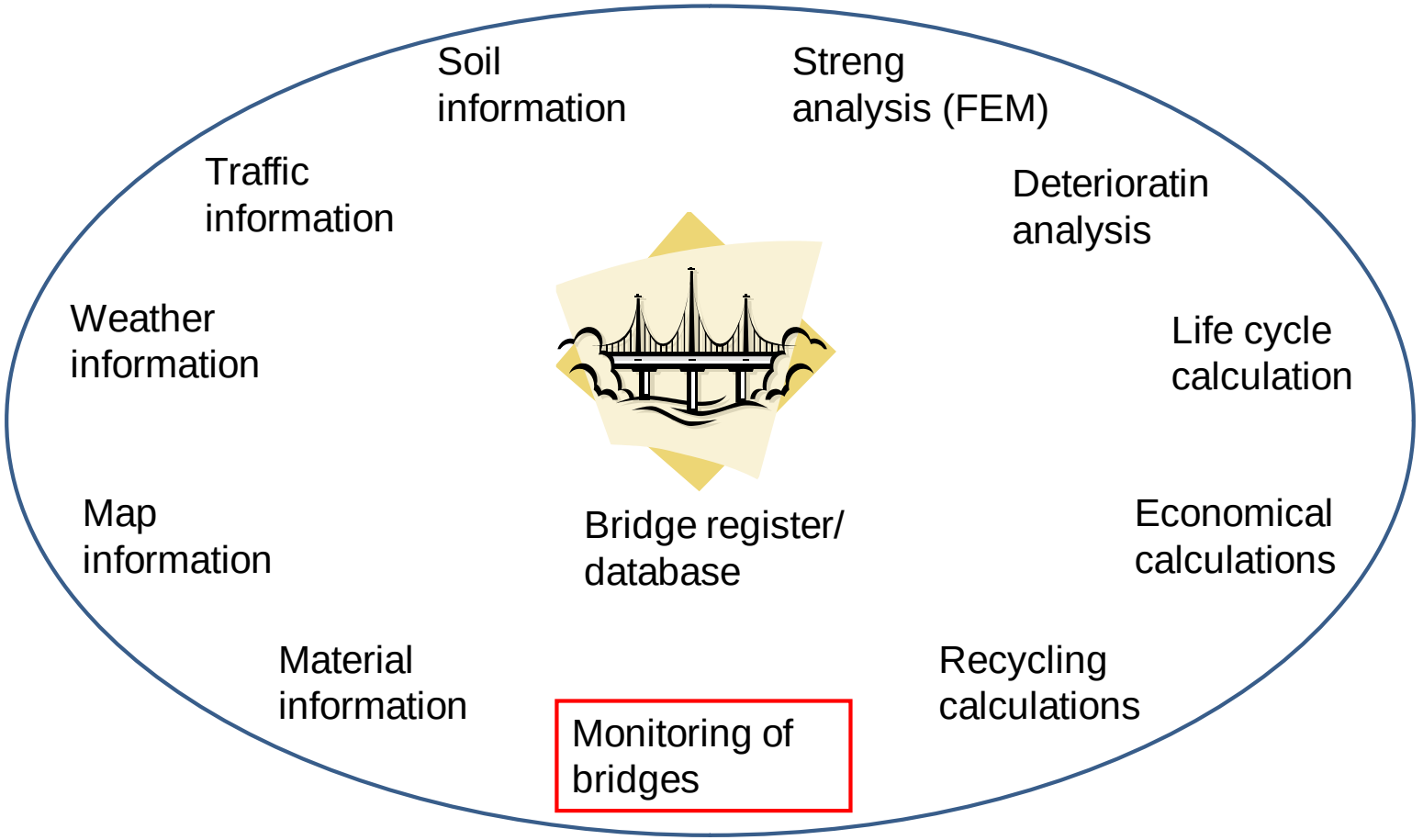
2. GHMSB, Global Management System of Bridges

- In Finland most of the bridges are **concrete bridges** also steel beam bridges have concrete deck. Therefore the deterioration of concrete and rebars is important to develop and automate.

- Steel bridges in Finland 6% (culverts 1%)
- Timber bridges 4 % (Fig. Vihantasalmi) 120/70)
- Stone bridges 1%

- **The deterioration analysis needs information e.g. about the weather, air humidity and salting**, which are not wise to copy to the bridge database

2. GHMSB, Global Management System of Bridges



3. GHMSB in Finland, Monitoring

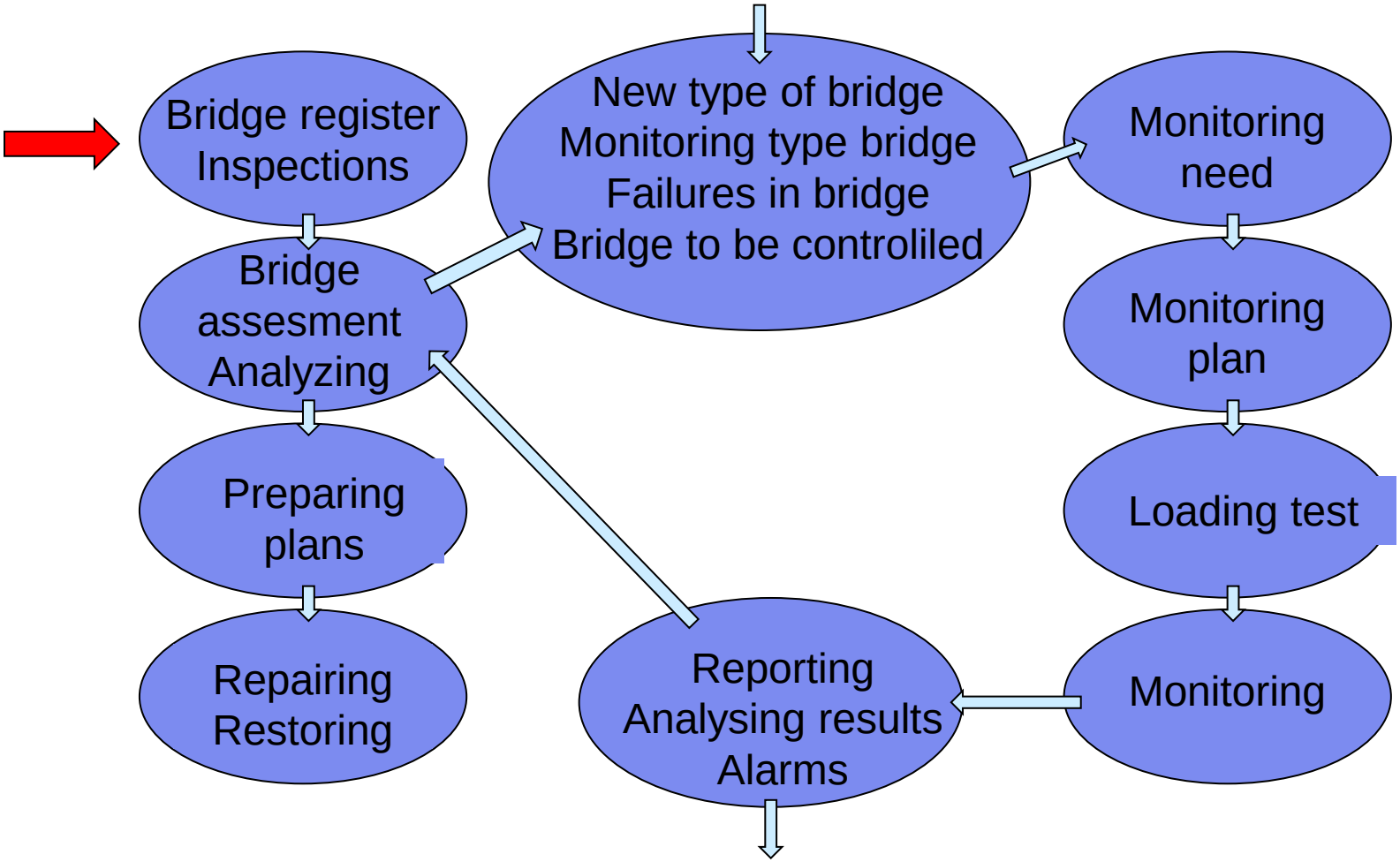
Monitoring of bridges can be divided into the following groups

- **Short term monitoring** for some days or some month
- **Periodical monitoring,** which will be repeated regularly or during inspections
- **Permanent monitoring,** which will continue for years or to the demolishing of bridge

3. GHMSB in Finland, Monitoring

- Short term monitoring will be performed, if there has been found **failures** from bridge or if the crossing traffic will be measured
- Periodical monitoring **will be repeated regularly** at least once in a year, or at least several times. The results will most probably include also rare occasions and the reliability is higher.
- Permanent monitoring will last many years and will produce **continuous data for analyzing**, but also it can be able to send **alarms** from the failures of bridges, traffic accidents or fires
- The systematic way is to monitor only one or some exemplar of each type in various weather conditions. The rest bridges can be analyzed with these exemplars of monitored bridges

3. GHMSB in Finland, Monitoring



3. GHMSB in Finland, Monitoring

- Monitoring of bridges will be, in the future, **a systematic way to gather continuously information** from many bridges and this is possible if **information, strength (FE model) and deterioration models of bridges have been made** and in addition the other analyzing tools and registers can be included in the platform

- In SITUEL project Simantics [3] was selected as the implementation tool for the common bridge platform.

- **Simantics is a platform for modeling and simulation** originally developed at VTT, but currently released and maintained as an open source tool by THTH (Association of Decentralized Information Management for Industry)

4. GHMSB in Finland, Bridge Register

- Bridge register in Finland is a basic data base and it includes **administrative, structural and geometric information**, but only a few of newest drawings are in digital format

- Almost all the **old drawings** have been scanned from micro films and are only in **picture formats**. Therefore no dimensions or material information can automatically be performed, but only looking manually from drawings.

- The bridge register includes **detailed inspection information about the condition of bridges**. The inspection in Finland is systematic work and also the people performing the inspections (inspectors) are educated and their work will be supervised and therefore the evaluation of condition and failures are uniform

4. GHMSB in Finland, Bridge Register

- **The information model** about the bridges is under development, the newest version has been published in 2013 [4].
- More development is still needed if all the information could be build in the model.

- Especially the automatic generation of strength model from information model is under development in many design and FE (Finite Element) programs.

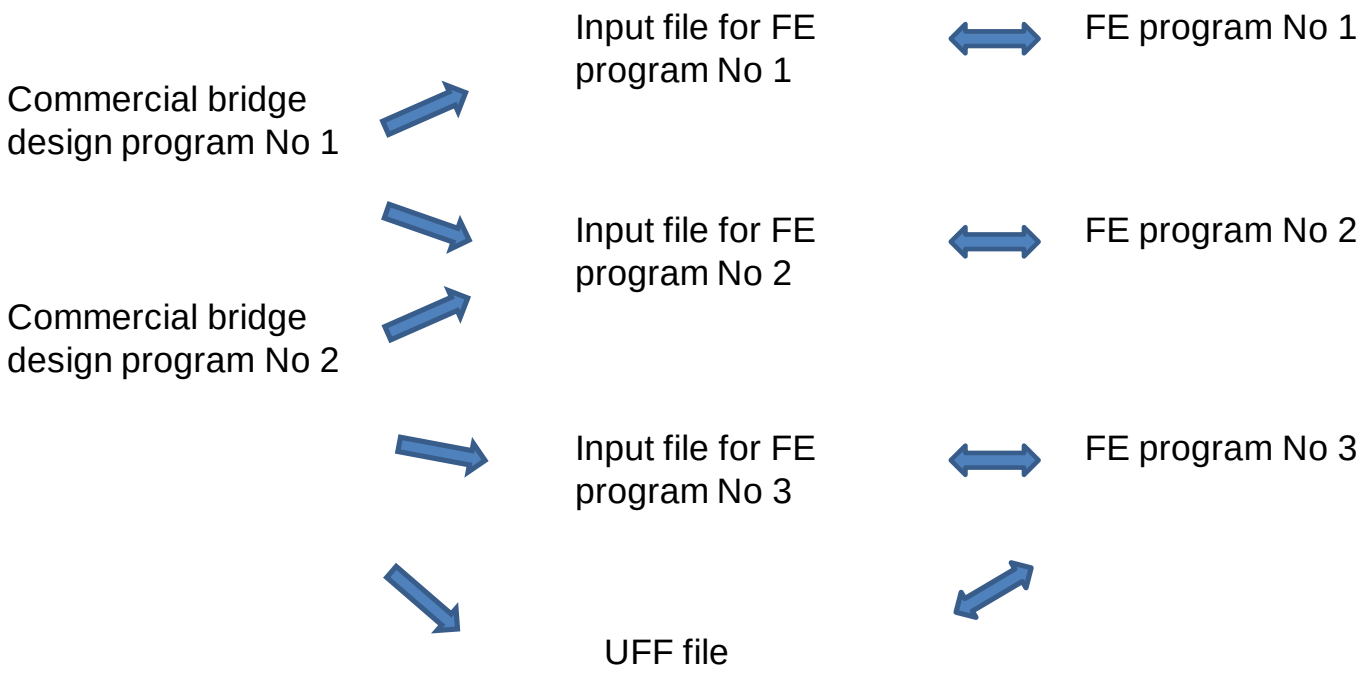
- The main problem of bridge register is that **the old bridge information, which is not in digital format, because the work is huge**.
- On the other hand **the digital information of newest bridges will be utilized after ten or twenty years**, because usually these bridges are in good condition for many years

5. GHMSB in Finland, Information model of bridges

- There are many types of information models for bridges.
- The building process of bridges begins with **planning, designing and analyzing of bridge.** The planning process includes the soil, traffic and architectonic research, but also economical calculations.
- The presentations will present mainly the **strength, deterioration and monitoring models of bridges**
- The strength model of bridge is usually FE (Finite Element) model
- Some **commercial bridge design programs can generate the input file for FE analyzing program,** but the link is working only in one direction, usually if modifying the FE input model the information model cannot be changed automatically.

5. GHMSB in Finland, Information model of bridges

- Some FE and design programs can produce UFF (Uniform File Format) files, but unfortunately FE programs include many other parameters to control analysis and to define e.g. material parameter.



5. GHMSB in Finland, Information model of bridges

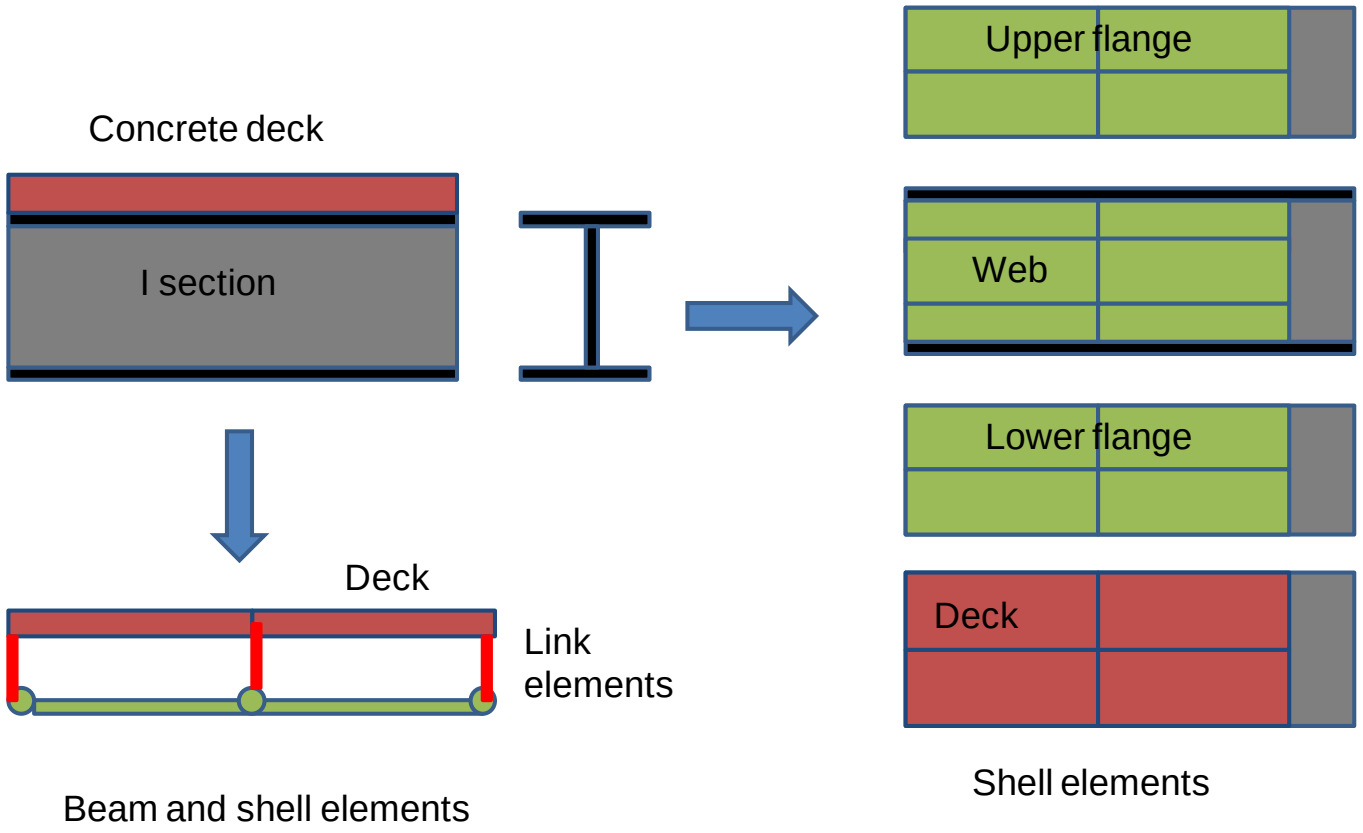
- The strength model of bridge is always a **simplified model of bridge** and does not includes all the details e.g. connection plates and bolts
-
- This is because **the FE programs have still size limitations** for the model especially if shell or 3d elements have been used in the model

- The new bridges can be designed using commercial design programs and then **the strength analysis can be done almost automatically using FE programs**.

- The system will develop more in the future, but unfortunately **the main problem of failures concerns old bridges, which does not include information or FE model.** The model should be created almost **manually using old calculations and paper drawings**

5. GHMSB in Finland, Information model of bridges

The FE model of bridge can be made by using beam or shell elements

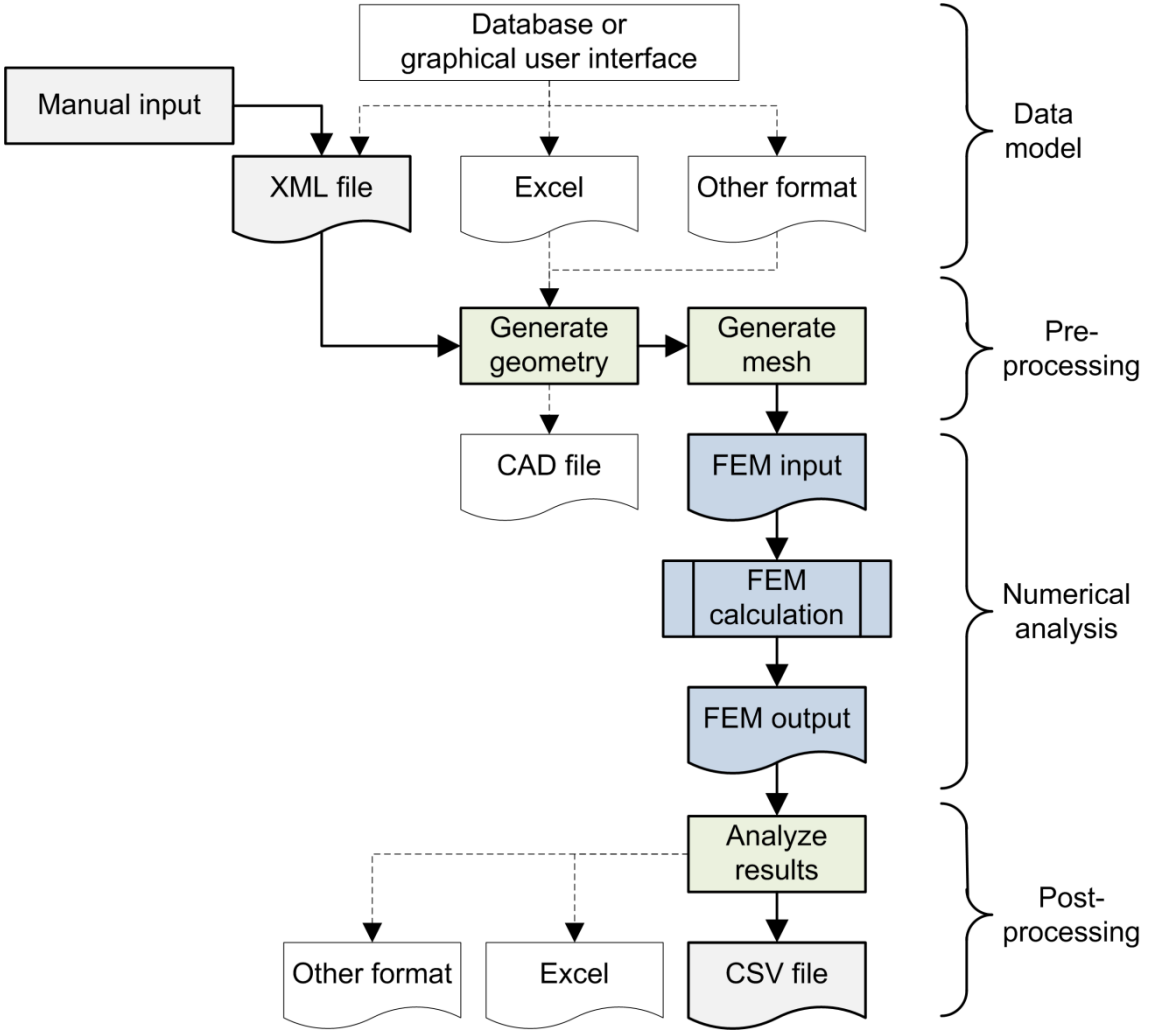


5. GHMSB in Finland, Information model of bridges

- In VTT in Finland there has been developed a method **to create FE model using only few parameters taking from Bridge register and drawings.**
- The model can be simplified or more complicated depending how many parameters and data values have been used in modeling.
- If the bridge model will be created always systematically and using **same component definition and co-ordination system, the model will be uniform and same methods e.g. moving load method can be used**.
- The FE mesh generator uses main bridge parameters and the code is **open source XML** file

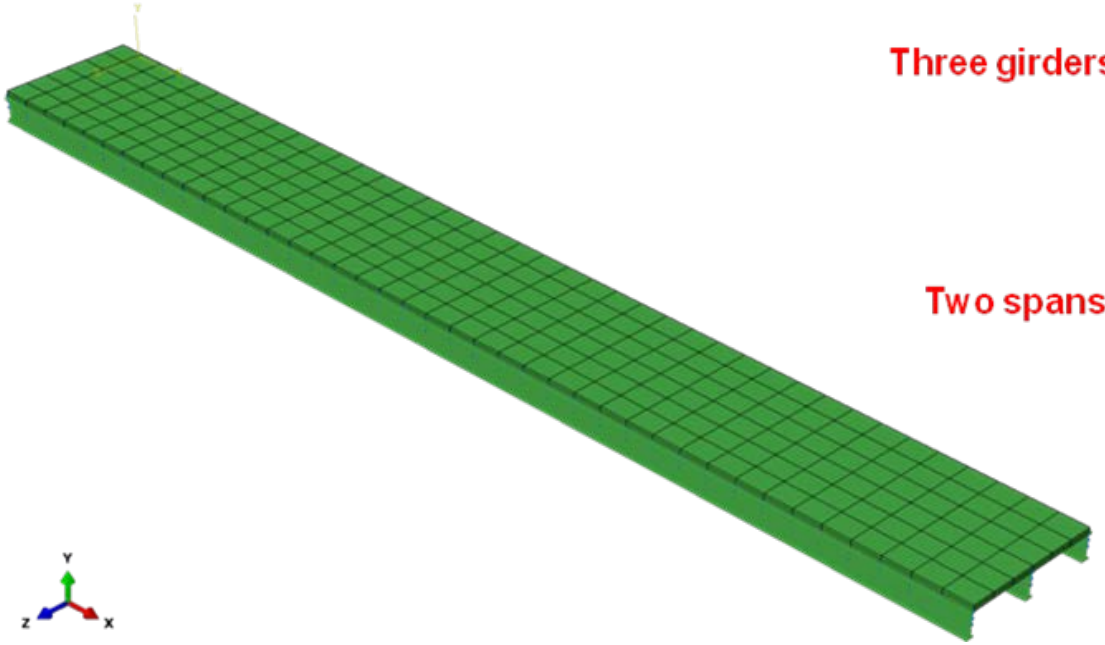
5. GHMSB in Finland, Information model of bridges

- At the moment generator creates Abacus code (FE program) using Python source code.



5. GHMSB in Finland, Information model of bridges

Automatic mesh generator to create simplyfied FE model for the bridge



Three girders

Two spans

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<?xml version="1.0"?>
<Database>

 <Girder id="3" name="Girder">
 </Girder>

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  <girders>
   <Girder ref="3" />
   <Girder ref="3" />
   <Girder ref="3" />
  </girders>
 <girderPos>0.1, 0.4, 0.4</girderPos>
 </Span>

 <Bridge id="10" name="Bridge">
  <spans>
   <Span ref="9" />
   <Span ref="9" />
  </spans>
 </Bridge>

 <CaseStudy id="12" name="Case">
  <bridge><Bridge ref="10" /></bridge>
 </CaseStudy>

</Database>
```

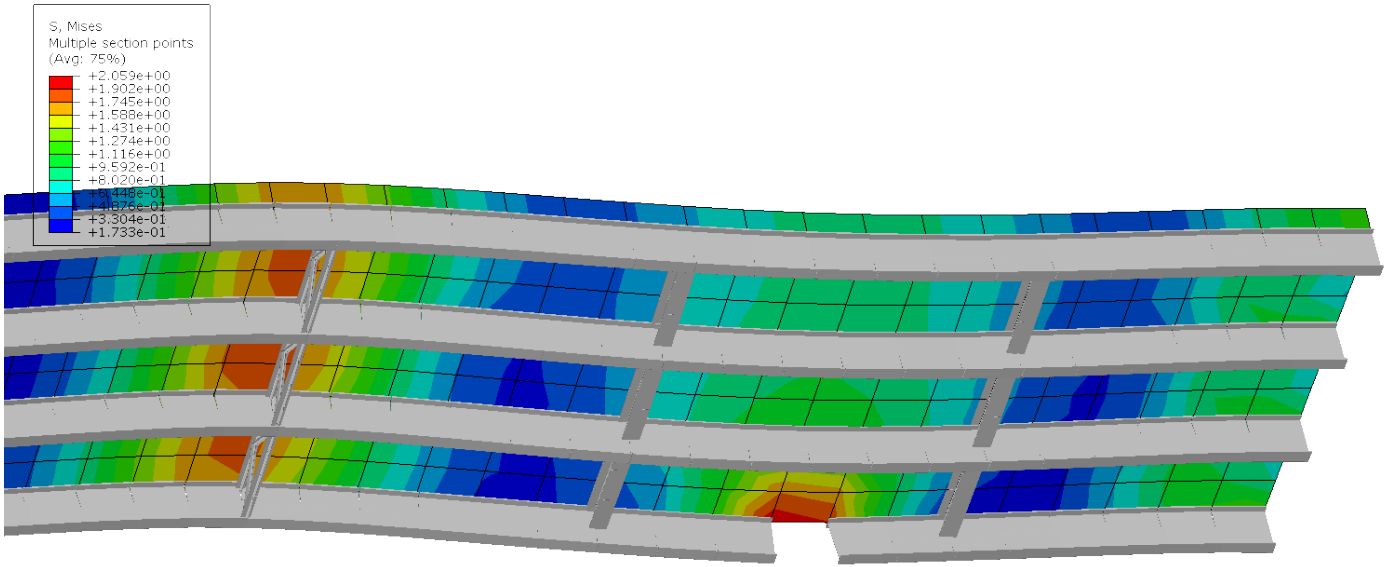
5. GHMSB in Finland, Information model of bridges

The following slides will show an example of automatically generated FE model of Makarla steel beam bridge in southern part of Finland. The model includes four main girders, cross beams and cross girders on supports

About 50 parameters
220 lines of XML code (7 kB)

5. GHMSB in Finland, Information model of bridges

- The bridge has been tested with heavy vehicles and the FE model has been calibrated for the load test results. The analyzing also includes failure analyzing e.g. for the occasion, that the one of the main beams will break according to Figure below.



6. GHMSB in Finland, Bridge load test

- **Monitoring of bridges should also include analyzing and reporting** to have the full advantage of measurements.
- While analyzing and then comparing the calculation results with monitoring results it is important to know **the loads crossing the bridge**, which can be done by performing load testing
- The bridge load testing will be done with one or many heavy vehicle, which total and axis loads and axis spaces have been measured.
- In the next Slide the weighing of axis loads have been shown

6. GHMSB in Finland, Bridge load test

6. GHMSB in Finland, Bridge load test

- In autumn 2013 about 10 steel beam bridges with wooden deck have been tested for heavier lorries (earlier 60 tons, nown76 tons)

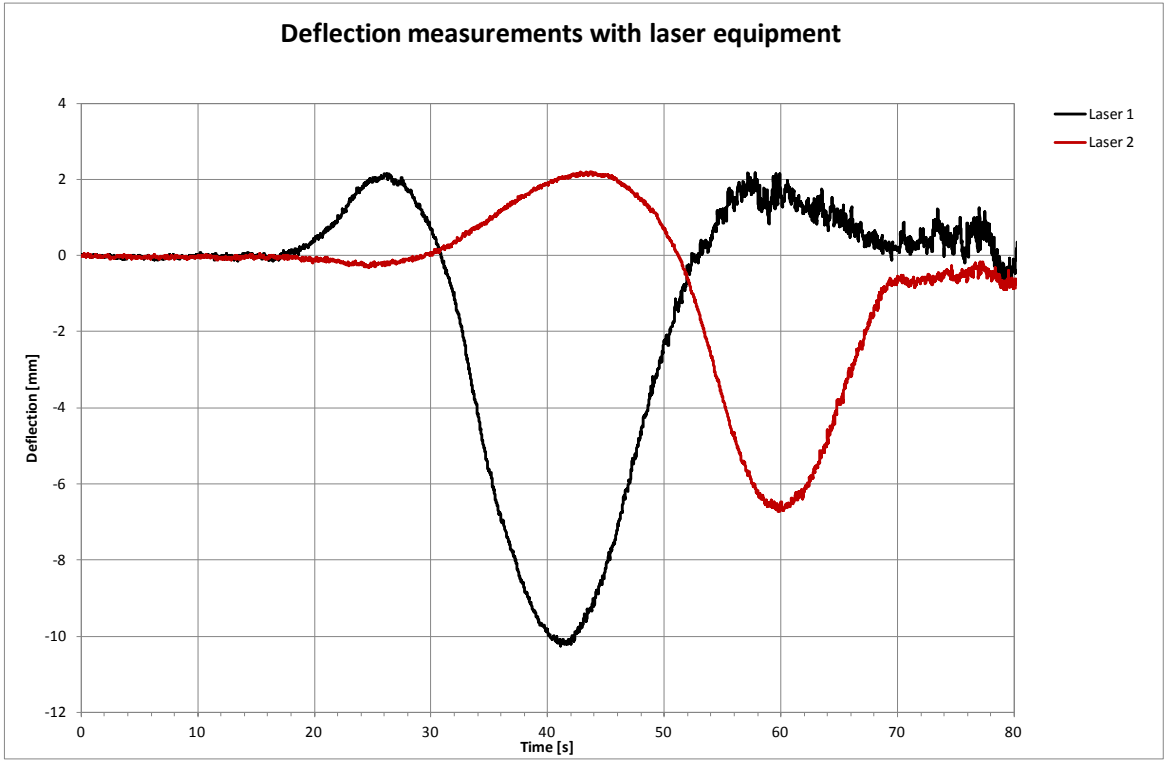
Two steering axes
Total 5+4 axes

6. GHMSB in Finland, Bridge load test

- Portable measuring equipments (strain gauges and laser deflection equipments) are working also with batteries for some hours

6. GHMSB in Finland, Bridge load test

- It should be observed, some bridge behave non-elastic e.g. suspension bridges and concrete bridges and therefore the load test should be done by increasing slowly the weight of vehicle



7. GHMSB in Finland, Monitoring Guide

- The monitoring guide will give detailed information about **how the monitoring should be performed**

- In Finland the first version of **Bridge Monitoring Guide** (only in Finnish) has been made to give detailed information for bridge owners, bridge designers and companies performing monitoring.

- The guide is intended to provide basic information and guidelines for bridge owners, municipal and transport authorities engineers and experts, and companies carrying out bridge monitoring on bridge condition and carrying capacities, in order **to facilitate the design and implementation of bridge or tunnel monitoring**.

7. GHMSB in Finland, Monitoring Guide

The sensors, measuring devices and methods used are presented in detail in the monitoring plan

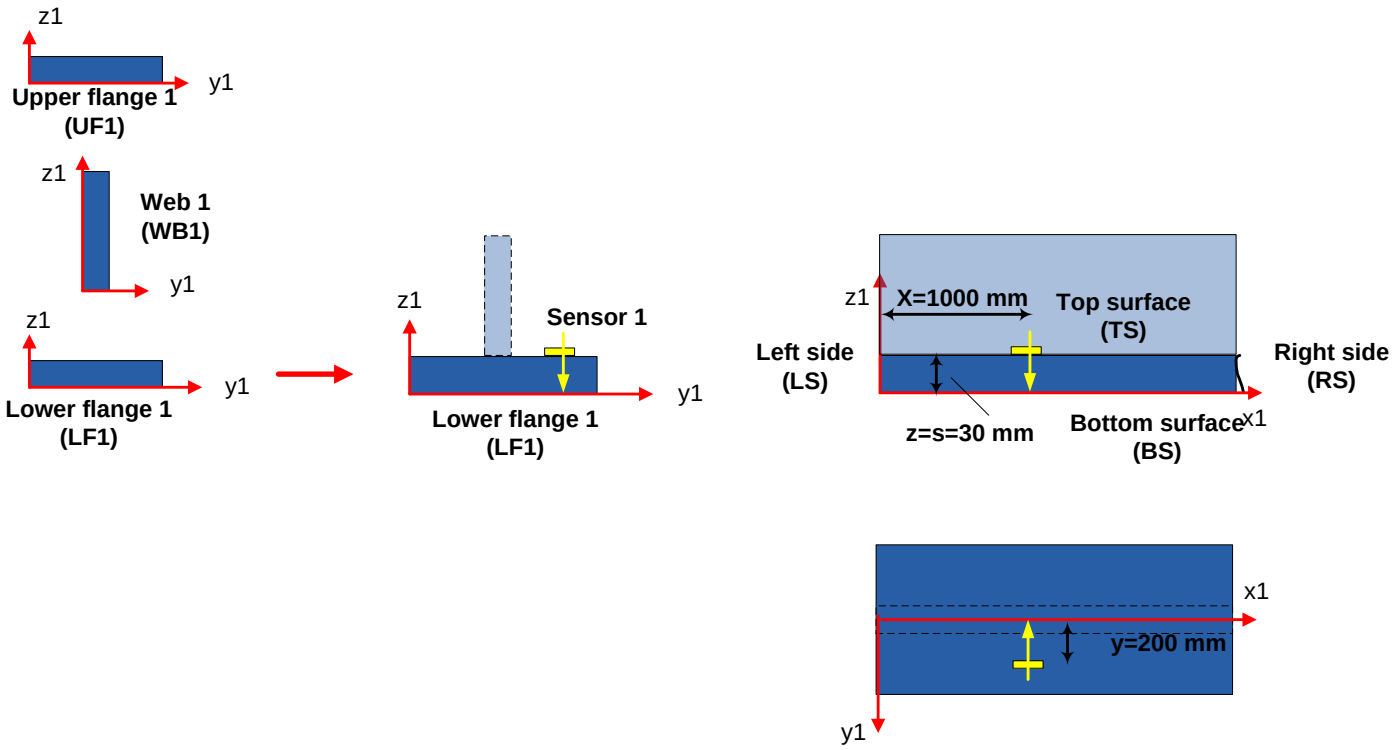
Sensor type	Measured variable	Usage/structure
Theodolite, tacheometry	Deflection	Deflection of bridge component
Deflection transducer	Movement, deflection	Movement of component or deflection of bridge
Laser movement device	Movement, deflection	Movement in plane
Rotating laser device	Movement, deflection	Deflection of bridge
Laser scaling	Location	3D figure of structure
Optical fibre	Movement, strain	Movement of component or deflection of bridge
Optical fibre	Strain, temperature	Stress, strain and temperature of component
Strain gauge	Strain (stress)	Strain or stress of component
Humidity sensor	Humidity	Humidity of air or material

7. GHMSB in Finland, Monitoring Guide

Thermocouple	Temperature	Temperature of air or component
Accelerometer	Acceleration, vibration	Vibration of bridge or component
Weather station	Weather information	Air
Force transducer	Force	Force between components
Induction sensor	Induction	Vehicle and axle recognition
Camera, video camera	Image, video	Traffic; bridge condition
AE sensor	Acoustic emission	Growth of fracture
Ultrasonic sensor	Fracture, welding failures	Quality of welds and concrete casting
Corrosion sensor	Electric currency	Corrosion of rebars

7. GHMSB in Finland, Monitoring Guide

- It is important, that the location of sensors have been given by systematic way to be able to perform automatic reporting and analyzing.



7. GHMSB in Finland, Monitoring Guide

- ´Example location description for a sensor located on the main girder

Name of bridge	Bridge no.	Basic component (span no.)	Structural element (main beam, cross beam ...)
River Bridge	101	SP2	MG2
Structural part (lower flange)	Surface (top surface)	Coordinates for the beginning part (centre point)	Additional parameters: Location/depth coordinates
LF1	TS x = 1000 y = 200 mm z = 30 mm	LG 0 mm	DP = 0 (x, y and z, no needed)
Short entry: **BR101/SP2/MG2/LF1/TS1000,200,30/LG0/DP0,0,0** (Bridge 101, Spacing 2, Main girder 2, Lower flange 1, Top surface x = 1000, y = 200 mm, z = 30 mm, LG 0 mm, DP x = 0, y = 0, z = 0)			

8. GHMSB in Finland, Data Analysis and Reporting

- The monitoring results **have to analyze** and simplify for reporting
- The raw time series are too complicated for making assessment of bridge condition
- In Table in next slide is given an example of **month report** (January 2013) where the maximum, minimum and average values for each sensor have been given.
- In addition the table includes information **how many events have been detected**, when either the triggering limit or the alarm limit have been passed

8. GHMSB in Finland, Data Analysis and Reporting

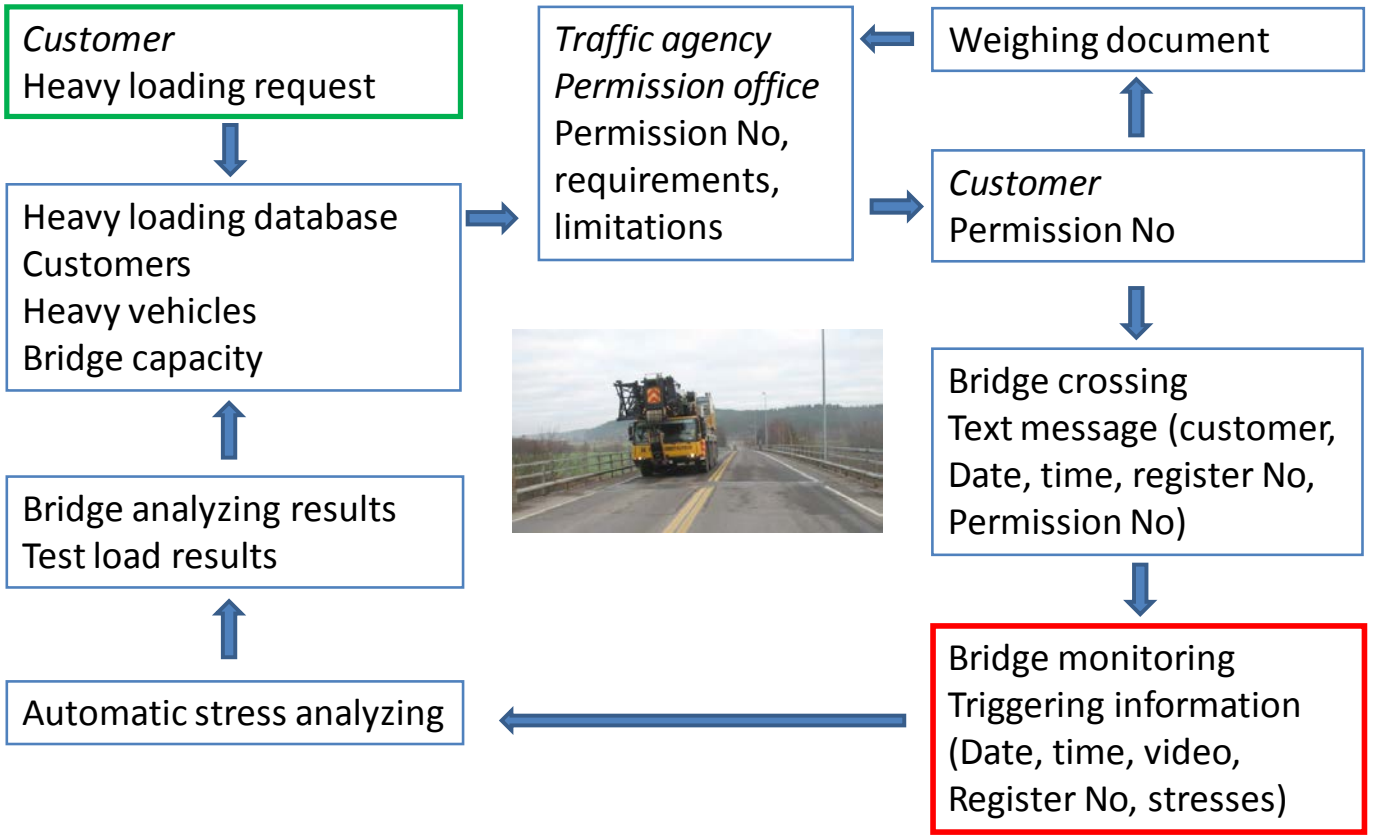
Bridge	No 999	Big bridge	Monitoring Time	January	2013		
Sensor	Unit	Maximum Minimum	Average	Triggering value	Events over Triggering	Alarm limit	Events over alarm limit
Deflection	mm	**50** -2	5.6	25 -5	100 1	40 -25	**1** 0
Strain	µS	120	80	100	80	200	0
		-20		-15	2	-100	0
Force	kN	100	50	80	5	200	0
		20		0	0	0	0

8. GHMSB in Finland, Data Analysis and Reporting

- The more advanced methods, which can be used in reporting and analysis are e.g. FE analysis, modal analysis and fatigue analysis
- The bridge monitoring can be used to gather information about the **traffic density, types of vehicles and weights of vehicle.**
- If the analyzing model will be combined to monitoring results, the weight of the vehicle should be defined.
- Monitoring equipment can be utilized to automatically **supervise the special heavy trucks,** carriages and mobile cranes crossing the bridge

8. GHMSB in Finland, Data Analysis and Reporting

- The flow chart to supervise heavy vehicles



9. GHMSB in Finland, Systematic Data Transfer and Saving

- The monitored data measured by monitoring equipments can be transferred from bridge to laboratory or other control room **by wired internet connection**, but usually the connection is not available especially in sparsely populated areas.

- The most common way today is to use **GSM modems** and mobile phone wireless connection, but the data transfer speed is limited and therefore all the data cannot be transferred.

- The data can be compressed and analyzed already **in the bridge situ** and then send the analyzed reports, alarms, and triggered time series. In SITUEL project in Finland, both wired and wireless connection was used, but also pre-analyzing was made with the PC on site.

9. GHMSB in Finland, Systematic Data Transfer and Saving

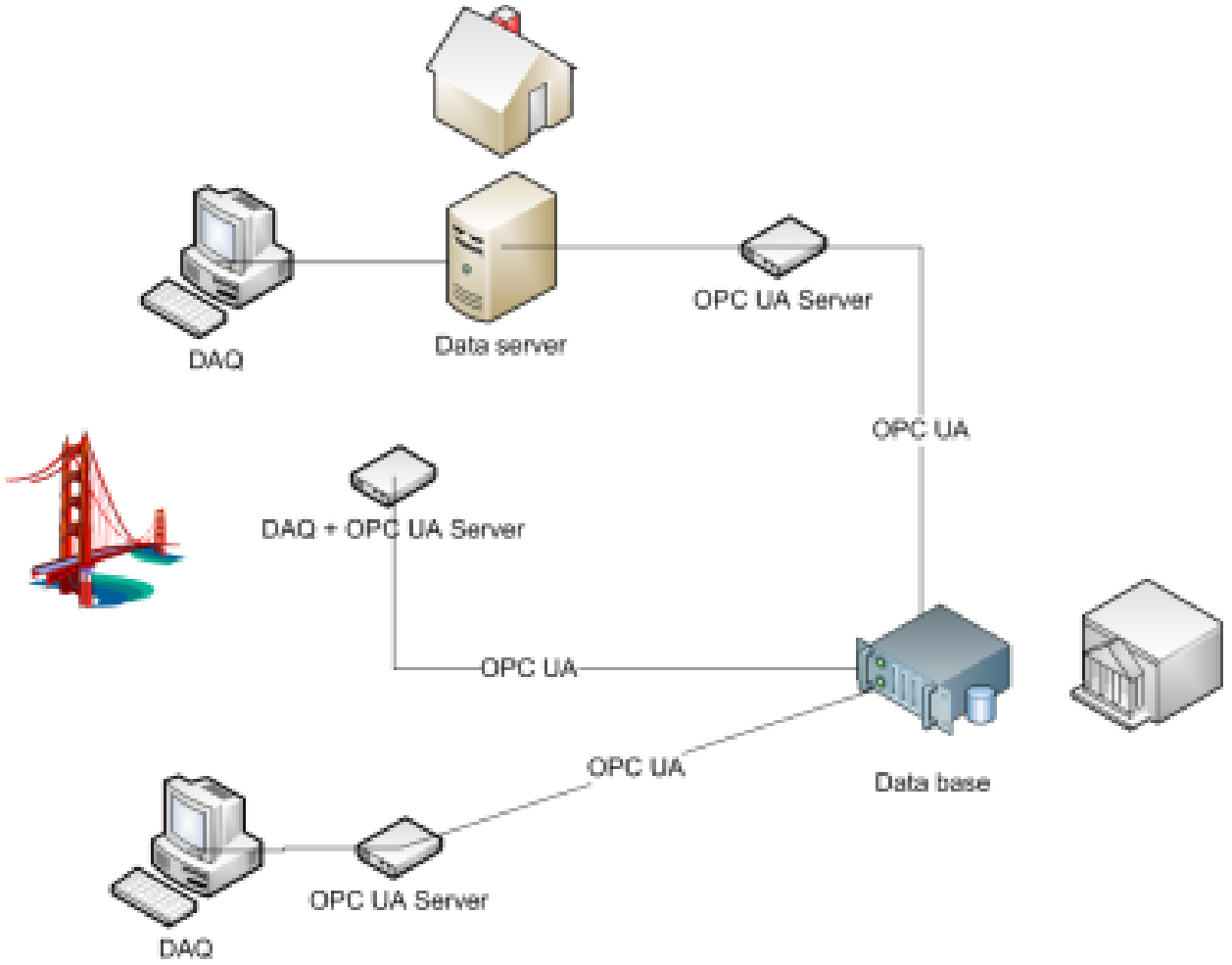
- The global monitoring system requires, that the data and data format **should be strictly and systematically defined** to be able to include system a lot bridges.

- Usually the data have been transferred to one direction from bridge to database in control room, but in the future also there should be **possibility to send commands to bridge**.

- **OPC (Open Platform Communication)** has been widely used in the automation industry for process control. Its outdated Microsoft DCOM based protocol is slowly changing to the newer OPC UA protocol. OPC UA enables the use of OPC on all operating systems and with all programming languages. **OPC UA is an IEC standardized (IEC 62541) protocol which is emerging from the automation industry towards a wider arena of applications**

9. GHMSB in Finland, Systematic Data Transfer and Saving

- A common interface in the use of bridge monitoring with the example of OPC UA

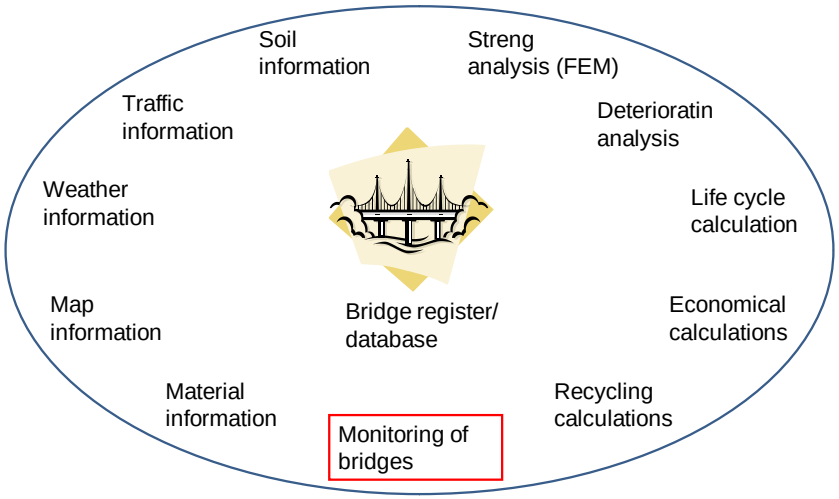


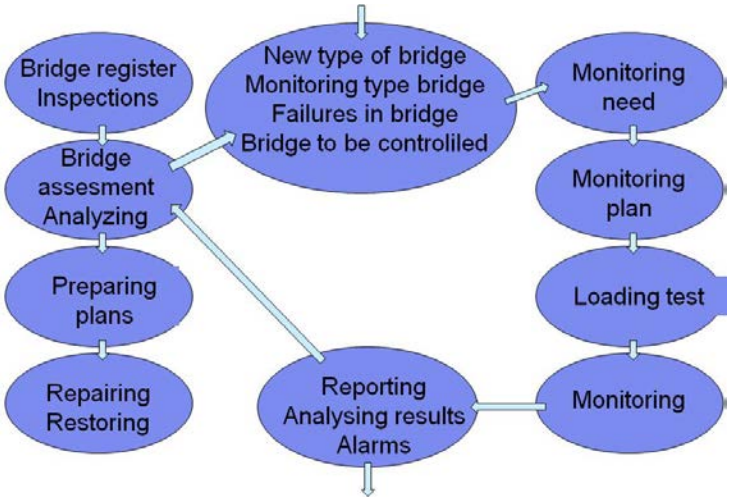
10. GHMSB in Finland, Summary and Conclusions

The main idea is to combine the following subjects

- **Bridge register and database, Bridge monitoring system, Bridge strength analyzing , Bridge deterioration analyzing, Bridge testing**

- The global management system of bridges (GMSB) is **part of the global management system of Infra** (GMSI).



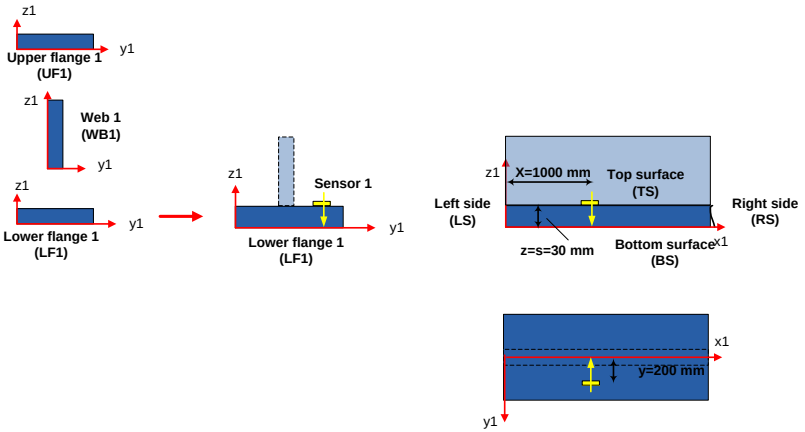


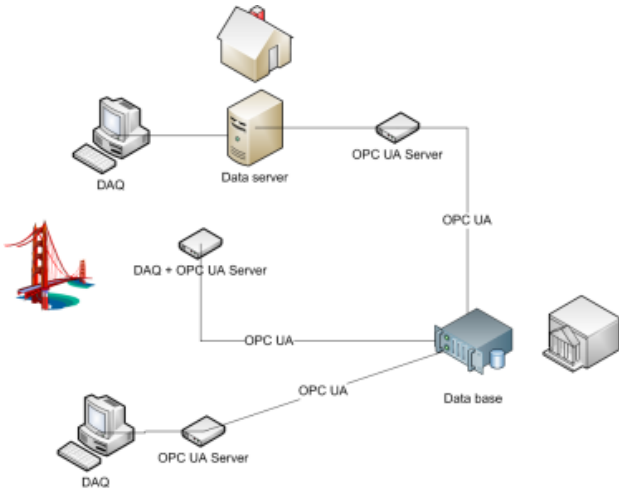
10. GHMSB in Finland, Summary and Conclusions

- Monitoring of bridges will be, in the future, **a systematic way to gather continuously information** from many bridges
- The FE mesh generator uses main bridge parameters and the code is **open source XML** file
- **The bridge testing will be done to calibrate the sensors** and to have information about the bridge behavior

10. GHMSB in Finland, Summary and Conclusions

- The monitoring guide will give detailed information about **how the monitoring should be performed**
- The monitoring results have to analyze and simplify for **reporting**
- **OPC (Open Platform Communication)** has been widely used in the automation industry for process control. It is also suitable for bridge monitoring





VTT creates business from technology