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Modeling Bus Load on CAN

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Master thesis

School of Information Science, Computer and Electrical Engineering

Modeling Bus Load on CAN

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Preface

This titled master thesis has been done at the Research and Development/System Architecture Dept. in Scania Technical Center, Södertälje, Sweden as a result of my studies at Halmstad University, Halmstad, Sweden.

I take this opportunity to thank several people who gave me their support during my Thesis preparation days at Södertälje and during my Post graduation at Halmstad.

Deep and special thanks go first to Jan Lindman, my supervisor at Scania, for his intensive comments, instructions, guidance, testing and tracking.

To Prof. Tony Larsson, my supervisor and examiner at Halmstad University for his patience and unlimited explanations, valuable instructions and support.

To David Holmgren, the RESA Group Manager for his instructions and comments.

To my father, mother and wife, I have received intensive and unlimited support from them.

Musab Al Hayani

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Abstract

The existence of high load and latency in the CAN bus network would indeed lead to a situation where a given message crosses its deadline; this situation would disturb the continuity of the required service as well as activating fault codes due to delay of message delivery, which might lead to system failure.

The outcome and goal of this thesis is to research and formulate methods to determine and model busload and latencies, by determining parameters such as alpha and breakdown utilization, which are considered as indications to the start of network breakdown when a given message in a dataset start to introduce latency by crossing its deadline which are totally prohibited in critical real time communications.

The final goal of this master thesis is to develop a TOOL for calculating, modeling, determining and visualizing worst case busload, throughput, networks' breakdown points and worst case latency in Scania CAN bus networks which is based on the J1939 protocol.

SCANLA (The developed CAN busload analyzer tool in this thesis) is running as an executable application and uses a Graphical User Interface as a *human-computer interface* (i.e., a way for humans to interact with the tool) that uses windows, icons and menus and which can be manipulated by a mouse.

The CAN Tool consists of: CAN_TOOL.fig (The Human-Tool Interface), CAN_TOOL.m, CAN_App.m, mydatabase.m, Plotting.m, BreakDown.m, ResponseTime.m, logfiles, associated databases and accompanying documents, such as this thesis report. This Tool is hoped that it will be useful but without any warranty.

For a description and instructions on how to use the tool, read intensively the report.

Please let the producer of the mentioned tool know of any improvements, changes or modifications that might be made.

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Thesis Supervisor: Jan Lindman

Title: Modeling Bus Load on CAN

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TERMS & DEFINITIONS

CAN	Controller Area Network
ECU	Electronic Control Unit
SA	Source Address
PG	Parameter Group
PGN	Parameter Group Number
COO	Coordinator to isolate buses & gateway specific messages.
BP	Busy Period
Tr	Response Time
Td	Deadline Time
Tp	Cycle Time
Node	Group of related functions allocated in one physical ECU
CANalyzer	CAN Analyzer tool for testing & visualizing real time bus response time
MATLAB	Programming Environment
OSI	Open Systems Interconnection model, which gives standard layers for communication functions.
J1939	Heavy vehicle standard for communication over CAN bus.
TTR	CAN Traffic Technical Report
Latency	Time remaining (which need to be used) to finish a message execution after its deadline
Utilization	Percentage of the achieved throughput over baud rate.
Alpha	Indication of how much useful slack time there is in the system
Breakdown Utilization	Bus breakdown point which happens when bus start to introduce latencies.
Priority in CAN Message	Importance value statically given to CAN messages.
Blocking Time	Time Delay of Message Execution due to suspension by higher priority message or due to wait for a free resource to use
OBD	On Board Diagnostic
DTC	Diagnostic Trouble Code
KWP2000	Keyword Diagnostic protocol
GUI	Graphical User Interface
SCANLA	SCANIA CAN Bus Load Analyzer (The Produced CAN Tool)

CHAPTER 1. INTRODUCTION

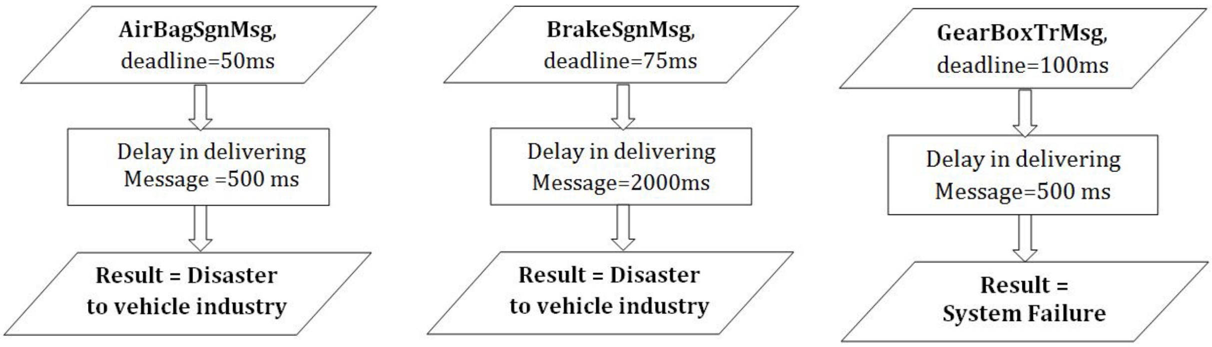
1.1 PROBLEM STATEMENT

As the development in automotive industry is growing rapidly, more sensors, CAN signals and CAN messages are added to the vehicle CAN bus networks and therefore more electronic control modules (ECUs) are added to those networks, which means more CAN bus networks are added to the vehicle.

As a result higher load will be introduced and should be calculated and checked to see its impact on CAN messages which could vary from delaying message delivery (latency) or stop delivering of those messages.

To get a better understanding of the nature of those CAN messages in Automation, let us assume the following examples in both hard and soft real time CAN messages; check out the following two examples:

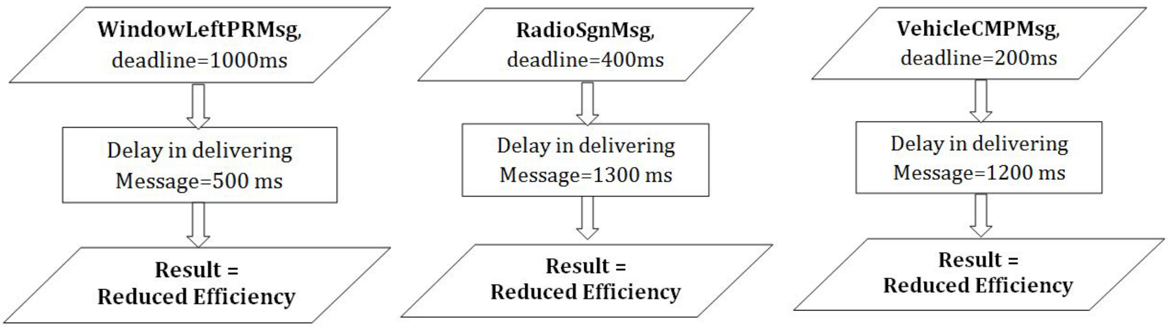
Ex1, if a specific **hard** real time CAN bus has received a load that drove some messages to cross deadlines; in other words, latency is introduced, such as:



Example-1 The results of delayed hard real time messages

Failing to deliver messages of hard real time nature could lead sometimes to serious consequences such as AirBagSgnMsg hard real time airbag message in example-1 which is considered as a disaster to vehicle industry that could lead to multi hundred million Krona loss as well as loss of lives, while a better case could lead to system failure such as GearBoxTrMsg hard real time gear box change message in example-1.

Ex2, if a specific **soft** real time CAN bus has received a load that drove some messages to cross deadlines; in other words, latencies are introduced, such as:



Example-2 The results of delayed hard real time messages

The delay in delivering soft real time CAN messages is somehow tolerated but lead to reduction in system efficiency but without dangerous consequences.

The consequences of latency in soft real time message is a reduction in the performance, efficiency and ability to provide continuous **comfort** service of the vehicle such as in WindowLeftMsgsoft real time left window motor message in example-2.

The existence of a relatively high bus load in the CAN bus will drive messages to cross their deadlines and therefore to introduce messages latencies.

High bus load on CAN → some messages will cross deadlines → Latency introduced → System faults/Failure.

Latency will delay or stop delivering instructions (messages) to critical real time communication to ECUs like BMS (Brake management system) which could lead to system failure.

We need to have an implementation for a performance evaluation and analysis of real-time applications and response time based on finding breakdown utilization points. At a breakdown point the system does not fulfill the required timing constraints. This is the utilization rate where deadlines are missed for the first time.

One more consequence of message latency is the setting of Diagnostic Trouble Code DTC after a specific message delay, which is unacceptable because those codes should refer to a system fault.

1.2 APPROACH SOLUTION TO THE PROBLEM

Our proposed solution to the mentioned problem in 1.1 will be based on the following approaches:

1. If we can get a response time analysis of message set that are arbitrating on the targeted CAN bus, then we will get to know exactly whether a specific message is introducing latency or not, therefore the dangerous consequences in section 1.1 when a hard real time message **AirBagSgnMsg** crosses deadlines could be located and specified.

2. If we can tune and move that response time analysis for different cycle time of same message set in a way that lead to get the response time analysis of breakdown point where the CAN bus network starts for the first time to introduce latency then we will get to know exactly the utilization point that a CAN network shall be kept under that utilization point.

3. If we can modify the attributes of the CAN message set just prior to run the mentioned response time analysis then we will be able to test any given attributes and retest again in a way that fulfils the needs in our design as well as keeping our CAN networks un hurt by latencies, therefore the dangerous consequences in section 1.1 when hard real time message **AirBagSgnMsg** crosses deadlines could be prevented.

Our targets' system behavior is:

1- For hard real time CAN signals and messages, preventing system faults and failures of latency causes (that could lead sometimes to disaster to vehicle industry).

2- For soft real time CAN signals and messages, preventing the reduction in the system efficiency which caused by latency in those CAN signals and messages

It is important to keep all CAN messages delivered within their correspondent deadlines to ensure the continuity of the service especially for hard real time CAN messages; therefore I decided to built a tool that can analyze CAN networks to see its load, breakdown load and catching latency if exists.

1.3 THESIS GOALS AND EXPECTED RESULTS

Based on the approach solution proposed in 1.2 and in order to keep all CAN messages delivered within their correspondent deadlines to ensure the continuity of the service especially for hard real time CAN messages; therefore I decided to build a tool that is capable of:

1- Simulating and modeling CAN bus load and message latencies

2- Showing latencies if they exist in the bus network. Most of normally loaded CAN bus networks introduce latencies; while the lightly loaded CAN bus networks of course are free from latencies. Some latencies can be tolerated while the others can't be tolerated and should be prevented based on the how much critical are the timing behavior of the signals embedded in those late CAN messages).

3- Analyzing of a given bus network to determine response time analysis of all messages under test which will improve our understanding on how a specific CAN bus network behave during different run, still or wake up modes .

4- Showing how much useful free slack time is there in the network

5- Testing a given network to determine by how much it could handle an extra load

The Tool should be able to model and visualize the busload and latencies of Scania CAN buses/messages using multiple combinations of Scania's (User Functions) Messages, and apply them in their worst case scenario.

We need to have an implementation of real-time applications analysis which is based on finding breakdown utilization points. At a breakdown point the system does not fulfill the required timing constraints. This is the utilization rate where deadlines are missed for the first time. With our implementation we observe the system behind the breakdown utilization; we observe the system behavior under overload conditions.

The ability to visualize latency of each message will intensively help to locate the point in time when a given message or a bunch of messages would cross their deadlines and as a result, visualizing latency would indeed help to overcome the reason behind it.

Calculation of the Breakdown Utilization will give us a value which indicates how much slack time there is in the network.

One of the main expected results is to determine parameters like ‘breakdown utilization’ and ‘alpha’ which are considered as an indications to the start of network breakdown when a given message in a dataset starts to cross deadline which is not allowed in critical real time communications.

1.4 PROGRAMMING TOOL ENVIRONMENT

I selected **MATLAB** as a suitable programming environment to model the whole TOOL and to compute data analysis, visualization, and numerical computation. MATLAB resolves technical computing problems faster than traditional programming languages, such as C, FORTRAN, and C++.

MATLAB is widely used in applications like signal and image processing, control design, communications, test and measurement, modeling and analysis, and computational biology.

CHAPTER 2. BACKGROUND

Controller Area Network (CAN bus network) is a serial communications bus network which is basically designed and manufactured to support simple and robust communications for Bosch's inVehicle bus networks.

In a regular vehicle, there exists tens of thousands of unique and distinct signals and most of them have the nature of real time and some of them are critical real time, where the CAN bus network have replaced their thousands of point to point wiring methods and integrated them into one to seven bus networks .

The CAN bus network is set among multiple electronics which helps translation and interfaces between multiple systems. Those electronics include CAN gateways, CAN embedded controllers, Hardware interface, and CAN converters.

Heavy duty vehicles did identify the CAN bus (especially the J1939 protocol) as powerful and the most reliable bus network ever used in what is known as (inVehicle communications).

Today every vehicle that is made in USA, Japan, Europe and Korea is equipped with at least two CAN bus networks [1]

In some countries such as the USA, implementing and using of CAN bus network is obligatory.

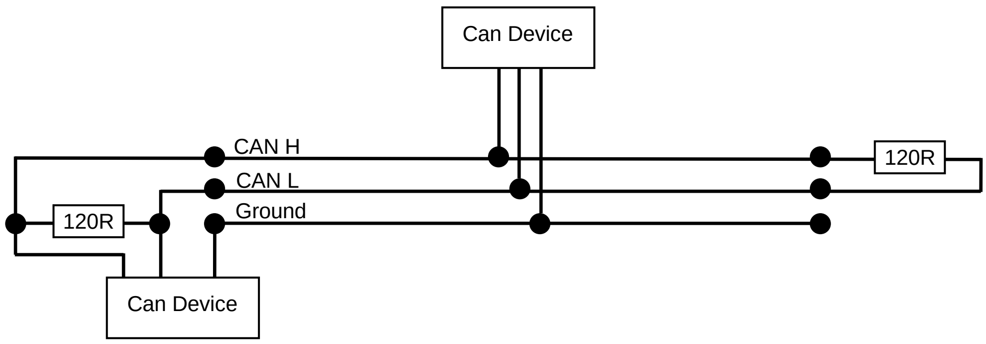


Figure 1 Typical CAN Bus

The above figure shows a typical CAN bus topology, here I shall say that it is necessary to terminate the bus at both ends with 120 Ohms. Those two resistors used to prevent reflections and to unload the open collector transceiver drivers.

2.1 WHY CONTINUE TO RELY ON 'CAN'

The communication needs in Automotive is completely different from that in many other networks. In automotive communication, we need to have better real time behavior and especially the delay should be totally deterministic in order to have a real time bus networking.

If we have a CAN bus network and there exist two nodes which want to transmit at exactly the same time, then the higher priority message (higher important message) will win the arbitration to seize the bus and therefore a guarantee to deliver a message in CAN bus network and as a result CAN bus is a deterministic network and is preferred in automotive communication where we have critical real time traffic which has to use a deterministic network to communicate , while the competitor network (Ethernet) is a nondeterministic network

The following list describes the characteristics of CAN networks:

1. Multi Master Bus (broadcast communication technique)
   Every node/ECU in the CAN bus transmits messages to all nodes, and each node filters out uninteresting messages and responds to only the wanted messages, which is compatible with the nature of sent messages which need to be broadcasted in general.

2. CAN is a Message based network
   This topology allows any node to send the same message or receive it, in other words it facilitates the addition or removal of nodes without extra embedded software.

3. Very cheap hardware and easy installation
   The CAN bus uses very cheap and easily installed twisted cable. 'Additionally, there is no need to have for example switches and/or hubs.

4. High Data Speed
   The CAN bus accepts range of baud rate, where the highest is 1 Mbits/s, which is slow compared to Ethernet 1-5 Gbit/s and USB 500 Mbits/s, but fast compared to RS 232 (100 Kbits/s).

5. Extremely high security level and high error detection and correction,
   The CAN bus produces an extremely high security level with a high error detection rate and we can assume that no data will be lost.

6. Continuity and reliability of the CAN bus even if node fail happens.
   The CAN bus will continue to run even if one or more nodes failed and a central node does not exist in the CAN bus network.

7. Synchronization is done with every packet transmission
   In a CAN bus, the network will get fully synchronized with every packet transmission by any node on the network.

2.2 SCANIA CAN BUS APPLICATION

At Scania, CAN bus applications have been built under the J1939 higher level protocol.

There exist three main CAN bus networks in Scania trucks (Red, Yellow and Green which are divided, based on their relative importance) that are interconnected with a coordinator gateway. SCANIA in addition has some other minor CAN buses for different purposes..

The first CAN bus network (**Red Bus**) is used for critical real time communications, this bus network connects powertrain ECUs, like the engine management system EMS, transmission management system TMS, Brake management system BMS.

The second CAN bus network (**Yellow Bus**) is used for less critical real time communications that connect chassis related ECUs, like All Wheel Drive system AWD, Locking and Alarm system LAS, Body Work system BWS, Body Chassis system BCS, and Extension to Body Builder Truck\Bus, as well as Visibility and Air processing systems and some other ECUs.

The third CAN bus network (**Green Bus**) is used for soft real time communications that connect Body ECUs, such as RTI Road Transport Informatics System, CSS Crash Safety System, AUS Audio System, CSS Automatic Climate Control, Auxiliary Heater System air to air and water to air, CTS Clock and Timer System

Some ECUs that are located on different bus networks may request data\messages from another bus network's ECUs; it is then gatewayed through high capacity ECU known as the Coordinator which connects different CAN buses together.

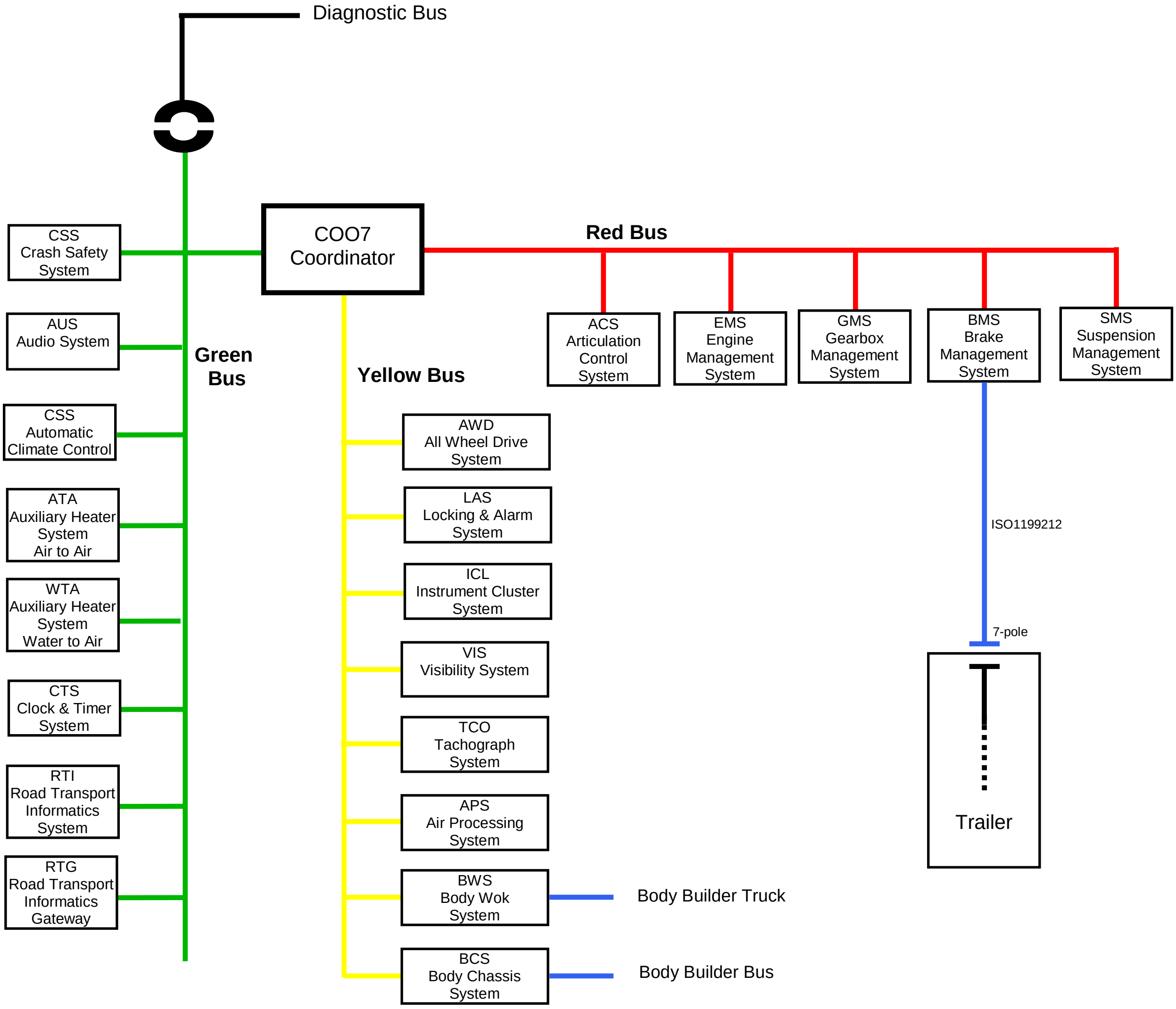


Figure 2 Schematic Diagram of Scania CAN Bus Networks Under J1939 Protocol

2.3 APPLIED J1939 PROTOCOL ON SCANIA CAN BUS NETWORKS

SCANIA is using J1939 protocol of standard communications and diagnostics in their heavy duty vehicle which is a standard maintained by the Society of Automotive Engineers (SAE).

The J1939 standard defines how information is transferred across a CAN bus network to allow different ECUs to communicate in-vehicle message information. The J1939 could be thought as a software specification that rides on top of a CAN bus.

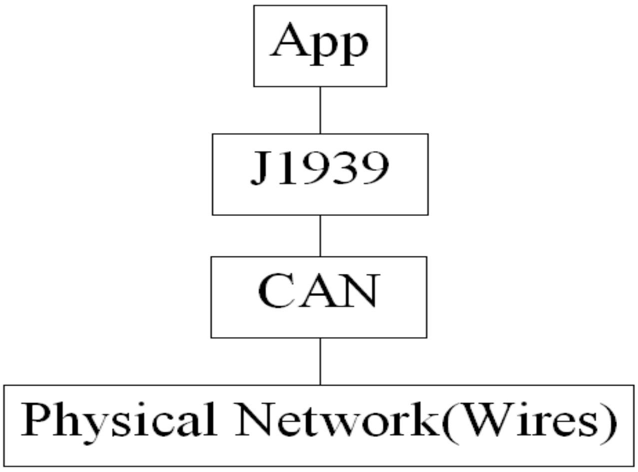


Figure 3 Standard J1939 network model

2.4 BUS NETWORK LENGTH

Bit Rate	Bus Length	Bit Time ($\mathcal{T}$)
• 1 Mbit/s	3o m	1µs
• 500 Kbit/s	100 m	2 µs
• 250 Kbit/s	250 m	4 µs

Table 1 CAN bus bit rate / length

The max line length of the CAN bus network is calculated primarily based on:

- The delay caused by looping of connected nodes of the given bus
- The delay of the CAN bus line
- The decrease in signal amplitude due to the CAN bus line resistance
- The differences in the bit time $\mathcal{T}$ caused by the tolerance oscillation between CAN nodes

2.5 J1939 SPECIFICATIONS:

- Highest error detection and fault tolerance.
- Cheap and easily installed twisted pair wire (Shielded)
- Bit rate of 250 - 500 Kbits/sec [16]
- Extended 29 bits Identifier

- Max. 30 ECUs could participate at a time in a network
- Best continuity and reliability for the above reasons

2.5.1 Message Format of J1939-21

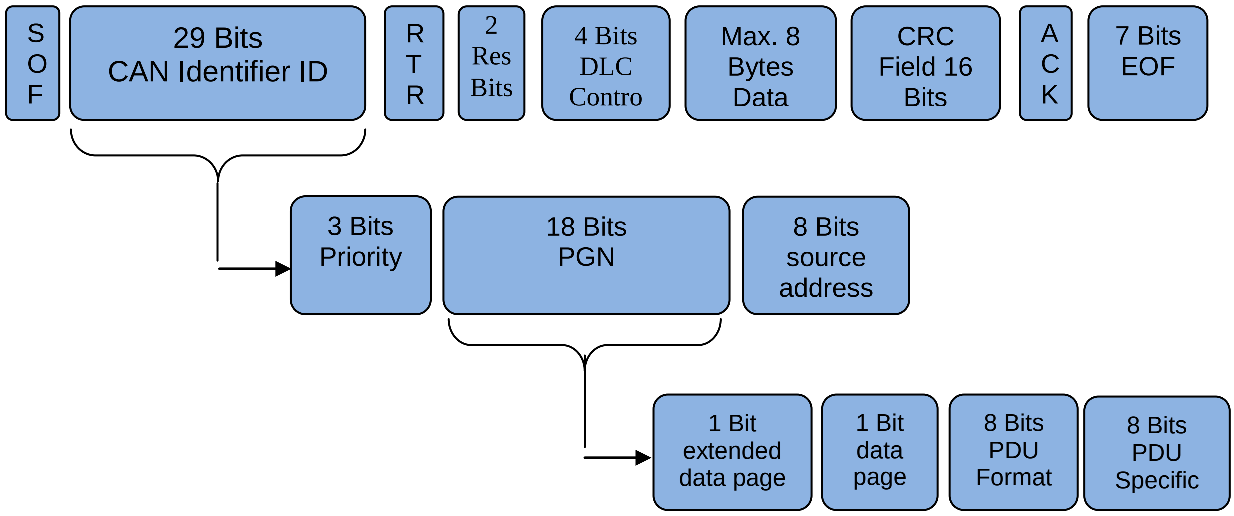


Figure 4 Typical Format of J1939-21 Message

- SOF
  It is a single dominant bit (start of frame, SOF) which marks the start of the frame message, and the main job for this bit is to synchronize all nodes located on the bus after idle case.

  Identifier

- CAN Identifier ID
  The Extended CAN consists of 29 bits identifier which determines the message priority and identity.

  The lower the identifier value, the higher the priority value.

- RTR
  It is a single remote transmission request, RTR, a dominant when another node requests information.

- DLC
  It is a 4 bits data length code, DLC and it contains the number of bytes of data to be transmitted.

- Data
  1 Up to 64 bits of data to be transmitted.

- CRC
  It is a 16 bits cyclic redundancy check, CRC which contains the number of transmitted bits of the data for error detection.

- ACK
  It is a 2 bits field, which consists of ACK slot bit and ACK delimiter

  The sender of a given frame transmits both of those bits with recessive status. While the receiver, when it receives the message correctly, would send back to the sender by sending a dominant bit in the ACK Slot.

- EOF
  It is a 7 seven recessive bits which is known as end of frame field, EOF, and the main job is to mark the end of a frame and to disable the bit stuffing.

The 29-Bit message identifier is partitioned into three main blocks and another 4 sub blocks:

The main three blocks are:

- 3 bits Priority field which equals to 8 priority levels
- 8 bits of Source Address (source ECU)
- 18 bits of PGN, Parameter Group Number to identify the use of the PG field, which is divided into four more sub blocks:
  - 1 bit extended data page.
  - 1 bit for page reference, currently page1 (2 pages available)
  - 8 bits of Parameter data unit **Format (PF)**
  - 8 bits of Parameter data unit **Specific (PS)**

2.5.2 Translation of PF and PS contents

- When PF = 0 – 239 PDU1 refers to a destination address in PS
- When PF = 240 – 255 PDU2 refers to an extension to PDU Format PF in PS

Translation of PF and PS contents**J1939-21 CAN Messages Arbitration**

2.5.3 1939-21 CAN Messages Arbitration

In the j1939 CAN bus architecture when more than one ECU starts their transmission at exactly same time after having sensing that the bus is idle, a Carrier Sense Multiple Access with Collision Avoidance CMSA/CD is applied for accessing the bus. Each message has 29 bits of ID or identifier and each ECU sends bit after bit of its identifier while monitoring the bus voltage level. As long as the transmitted bits from those ECUs are similar, nothing happens.[12]

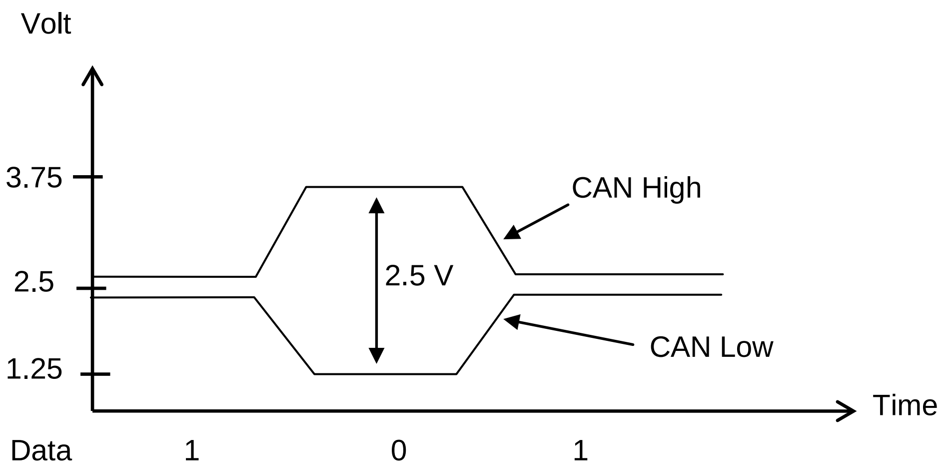


Figure 5 CAN Dominant (0) & Recessive (1) in term of Voltage

There are two voltage levels: the first is low and called dominant and the second is high and called recessive. The dominant bits will always win the bus and at that time if the ECU which transmits the recessive bit while encountering a dominant bit in the bus, then this ECU will directly stop transmitting and wait until the bus returns to idle. Therefore at the end, only one identifier will win the arbitration and gets the bus and as a result we see that the lower the identifier, the higher the priority.

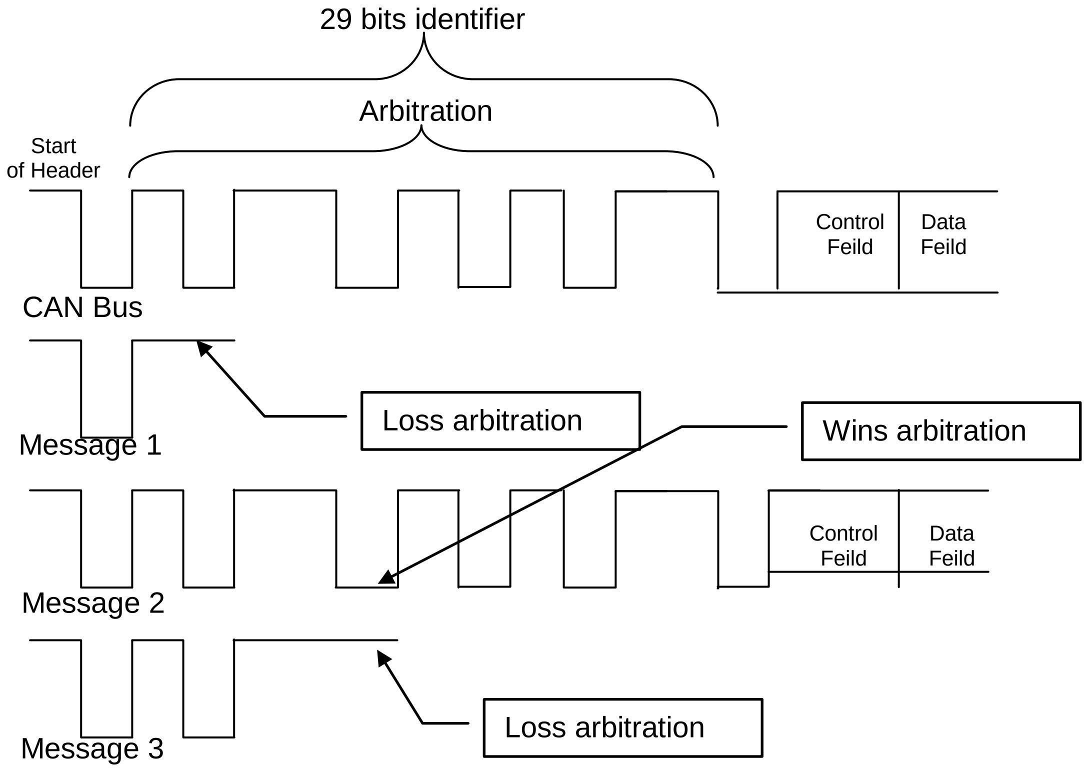


Figure 6 Typical CAN J1939 messages arbitration

2.6 STATE OF THE ART

Heavy duty vehicle manufacturers build their J1939 CAN bus networks based on common standard limitations as below:

1- Max busload utilization 80% of the CAN bus network (so that enough slack time are there for diagnostic messages, error message, overload message, etc) [13]

2- Max. Network length of 40 meters[16]

3- Bit rate of 250 – 500 Kbits/sec[16]

4- Max. 30 ECUs could participate at a time in any given CAN bus network[16]

Manufacturers have set a standard for the setting of 'Diagnostic Trouble Codes', after a specific amount of time such that for wake up mode, Tdtc> Tdtc_wakeup ms while in normal running mode, Tdtc> Tdtc_normalrun if a given a message that hasn't got into the bus network (deadlines crossed), those DTC Codes refer normally to either 1) a specific system fault or 2) simply the CAN bus has been loaded to the point that prevented a specific message from getting into the bus.

Therefore, it is recommended to examine why a given DTC Code was sat and what is the reason behind it. Searching through scientific papers did not show such a tool to determine the breakdown utilization that helps in preventing the setting of DTC Codes (of high load reason). Instead, the case is to examine some other factors (such as priority level of a given message which sets the DTC code, or the cyclic speed of that given message) and by changing those factors, this will overcome the reason and switch off that DTC Code if the reason was a high busload which introduces latency.

2.7 CLOSELY RELATED WORK

I have referred to the following research papers which I consider the best in this field:

- *Controller Area Network (CAN) Schedulability Analysis: Refuted, Revisited and Revised*

  Prepared by:

  Robert I. Davis and Alan Burns
  Real-Time Systems Research Group,
  University of York, England

- *Guaranteeing Message Latencies on Control Area Network*

  Prepared by:

  Ken Tindell and Alan Burns,
  Real-Time Systems Research Group,
  University of York, England

- *CAN Network Utilization,*
  Busload calculations for SESAMIM – Red Bus,
  RESA09002
  Internal Scania document

Those above papers make it possible for a researcher to get benefits from the Scheduability Analysis of CAN bus (first paper) which was developed to determine the worst case response time of any message within the CAN network and as a result it would be possible to calculate message latency (second and third papers) that are valuable in our goal towards preventing the network from falling under non schedulable network case.

CHAPTER 3. LOAD ANALYSIS MODEL

To simulate and model CAN bus load, we need to show each message latency if it exists in the bus network and how much useful free slack time is there in the network by calculating 'alpha' and 'breakdown utilization' that will be used to test a given network to determine by how much it could handle an extra load, therefore the modeling will be built up step by step.

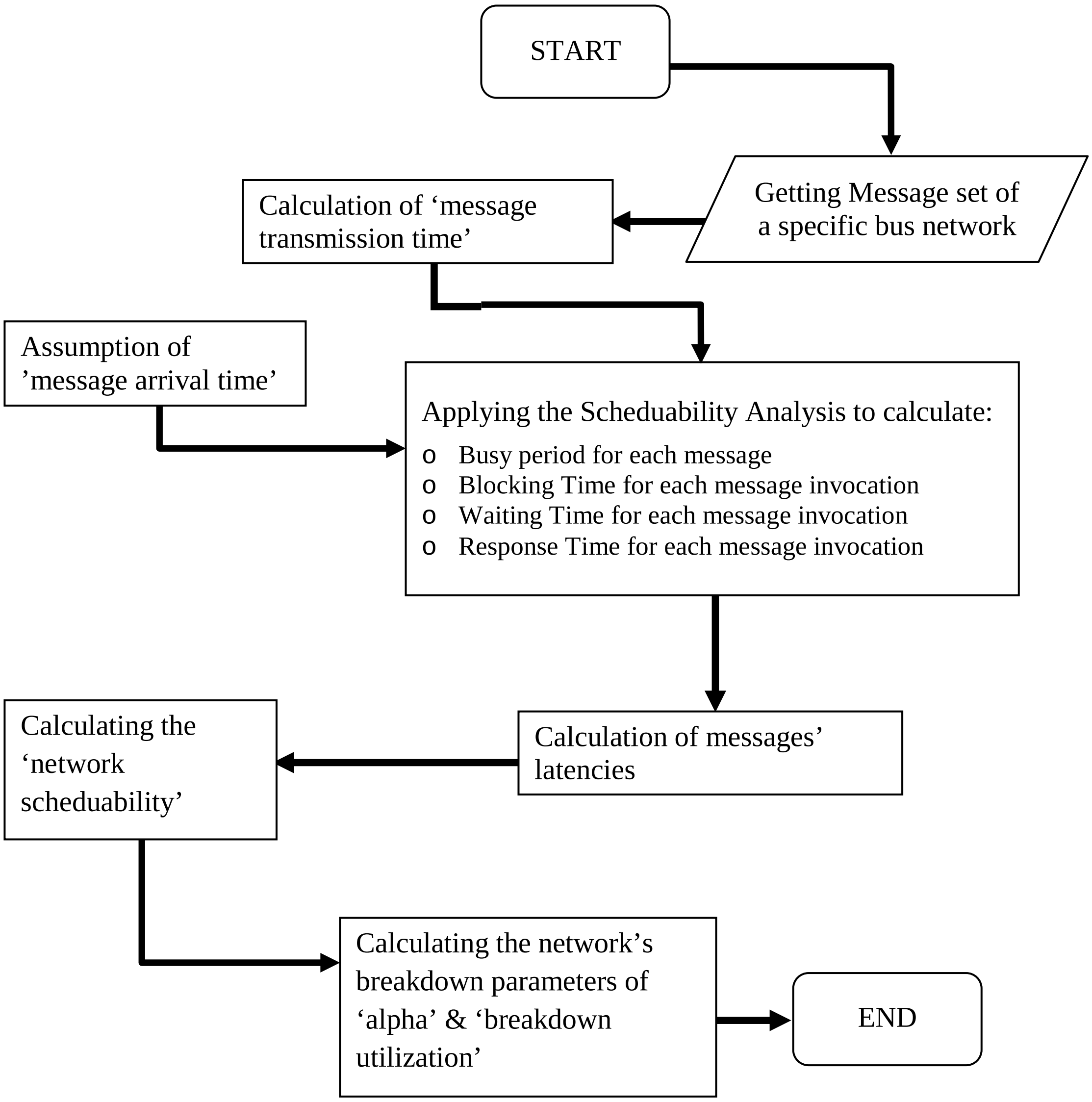


Figure 7 **Flowchart of the 'Mathematical Solution' to model CAN bus load**

3.1 ASSUMPTION OF MESSAGES' ARRIVAL TIME

A worst case assumption is always the case with respect to message arrival time.

A scenario is assumed where all messages arrive at the same time, this case would introduce the longest busy period of response time for those messages.

3.2 CALCULATION OF MESSAGE TRANSMISSION TIME

A worst case calculation with regards to bit stuffing is assumed to get the worst case message transmission time.

For extended 29-bit identifiers:

$$C_m = (80 + 10S_m)\mathcal{T}_{bit}$$

Equation 1 - - - - Message transmission time

C_m Max. transmission time of a message with 29 bits identifier

τ_{bit} Transmission time of one single bit

S_m Number of bytes of the data message

3.3 APPLYING THE SCHEDUABILITY ANALYSIS

To calculate the worst case response time and busy period for bunch of messages/user function is based on:

1- CAN bus is a fixed priority non preemptive scheduling bus

2- The whole busy period for each message should be examined.

The concept of a *busy period*, introduced by Lehoczky [5], is fundamental in analyzing worst-case response times; a priority level-*m* busy period is defined as follows: [1]

- Waiting time starts at some time when a message of priority *m* or higher is queued ready for transmission and there are no messages of priority *m* or higher waiting to be transmitted that were queued strictly before time and is given by the following recurrence relation [1]

$$w_m^{n+1}(q) = B_m + qC_m + \sum_{\forall k \in hp(m)} \left\lceil \frac{w_m^n + J_k + \tau_{bit}}{T_k} \right\rceil C_k$$

Equation 2 - - - - Message Waiting time / Relative

w_m Waiting time of the examined message m

q Invocation number of the message m

B_m Max. Blocking time of lower priority message than m

T_k Cycle time of all higher priority messages than message m

J_k Jitter of all higher priority messages than message m

C_k Transmission time of all higher priority messages than message m

C_m Transmission time of the examined message m

$w_m^0 = B_m$ Initial value

- It is a contiguous interval of time during which any message of priority lower than *m (queuing time)* is unable to win arbitration and to start transmission.[4]

$$B_m = \max_{k \in lp(m)} (C_k)$$

Equation 3 - - - - Message Max. Blocking time / Relative

B_m Max. Blocking time of lower priority message than m

C_k Transmission time of message set

- It ends at the earliest time when the bus becomes idle, ready for the next round of transmission and arbitration, yet there are no messages of priority *m* or higher waiting to be transmitted that were queued strictly before time . [1]

However, a higher priority message can be forced to wait for transmission when message *m* completes transmission and therefore the busy period can become longer due to the fact that CAN bus does apply the Fixed priority non preemptive scheduling, therefore we have to check for multiple instances of a message *m* that would become ready for transmission, just before the end of the busy period is per the recursive relation below [1]:

$$Q_m = \left\lceil \frac{t_m + J_m}{T_m} \right\rceil$$

Equation 4 - - - - Number of message invoications

Q_m Number of message *m* invocations to be examined under busy period

t_m Busy period time of the examined message m

J_m Jitter of examined message m

T_m Cycle time of examined message m

- The length of the priority m message's busy period that would be examined is given the following recurrence relation [1]

$$t_m^{n+1} = B_m + \sum_{\forall k \in hp(m) \cup m} \left\lceil \frac{t_m^n + J_k}{T_k} \right\rceil C_k$$

Equation 5 - - - - Message Busy Period

t_m Busy period time of the examined message m

B_m Max. Blocking time of lower priority message than m

T_k Cycle time of all higher priority messages of m and over

J_k Jitter of all higher priority messages of m and over

C_k Transmission time of all higher priority messages of m and over

$t^0 = C_m$ Initial value

The relative response time of a priority m message for each instance is given by:

$$R_m = J_m + w_m + C_m$$

Equation 6 - - - - Message Response time / Relative

R_m Worst case response time of the examined message m

J_m Jitter of examined message m

w_m Waiting time of the examined message m

C_m Transmission time of the examined message m

The worst case response time for priority m message through all invocations is given by:

$$R_m = \max_{q=0..Q_m-1} (R_m(q))$$

Equation 7 - - - - Message worst case response time

R_m Worst case response time of the examined message m

R_m(q) Response time of the examined message m for a given invocation q

q Invocation number of the message m

Q_m Number of message m invocations to be examined under busy period

3.4 CALCULATION OF LATENCY

Latency which is defined as the time remaining (which needs to be used) to finish a message execution after its deadline and is computed for each 'Message invocation' during the whole of the **busy period** is given by:

$$L_m = R_m - D_m$$

Equation 8 - - - - Message Latency time

L_m Latency of the examined message m

D_m Deadline time of the examined message m

R_m Response time of the examined message m

Note: A message deadline time is assumed to be equal to cycle time of a message.

Typically, Latency for a specific message invocation is equal to the subtraction of relative deadline D for priority *m* message from its relative response time *R*.

Latency visualizing helps the User to know exactly how messages behave during the wake up mode and in the run mode which is considered one of the outcomes and goals of this thesis.

3.5 CALCULATION OF ALPHA & BREAKDOWN UTILIZATION

3.5.1 Introduction

We need to have an implementation for a performance evaluation and analysis of real-time applications based on finding breakdown utilization points. At a breakdown point the system does not fulfill the required timing constraints. This is the utilization rate where deadlines are missed for the first time. With our implementation we observe the system behind the breakdown utilization; we observe the system behavior under overload conditions.[17]

3.5.2 Definition

The value of 'alpha' could be defined as **a relative quantity of a maximum load we could add to network until it introduces latency compared to the existed load.**

3.5.3 Translation

The translation of the said definition is by having for example a network with 'existed load= 24%' and 'alpha =2' means that the breakdown point is 2x24% = 48%

a value of alpha close to but greater than 1 indicates that although the system is schedulable, there is little room for increasing the load. The 0 value for alpha for the bus speed indicates that no value for breakdown utilization can be found (a non schedulable system) [2]

'alpha' is an indication factor of how much useful free slack time there is in the network which an extra load could benefit from until network introduces latency, it is a maximum value such that when the message periods are divided by alpha the system remains schedulable (i.e. all latency requirements are met). [5]

3.5.4 Possibilities

alpha=0 A non schedulable system, no value for breakdown utilization can be found

alpha=1 A schedulable system and there is no useful room for increasing the load.

alpha>1 The system is schedulable, and there is a useful room for increasing the load based on the how much alpha is greater than 1. (The greater the 'alpha', the greater the useful free slack time in the network, the greater the load we could add)

3.5.5 Modeling

We start a new simulation by running the scheduability analysis and checking the scheduability of a network after another, If the system is schedulable (the normal case), then we start by dividing each message cycle in a given bus network with step counter called Beta (started with 1 and increased with a counter 'resolution' of 0.1) then we run the mathematical scheduability analysis and check results, if the latency requirements still met, continue by increasing the step counter and running the mathematical scheduability analysis and check results until the latency introduced in the bus.

The value of that step counter at this point is our targeted 'alpha' of that bus and the bus utilization at this point is the 'Breakdown Utilization' of that bus.

if the given network is not schedulable (the non-normal case), then its associated 'alpha' is equal to zero (a non schedulable system).

Breakdown utilization is the bus breakdown point, which happens when the bus starts to introduce latencies, and computed by the percentage of <u>max</u> throughput (achieved using alpha point) over the bus bit rate.

3.6 FURTHER BUSLOAD

Normally, modeling of the CAN busload will not take into account the diagnostic messages load on the bus. Most of those messages are only allowed when the vehicle is in ''still'' mode. For KWP and UDS diagnostic messages, we locate the server cycle to each diagnostic message (sporadic message), however it is difficult to calculate their exact load because it depend on how many servers do we intend to initiate and how many commands will we activate at a time, but in reality there are a minimum of two servers initiated at a time which are sending multi packet messages with transport protocol <u>and</u> therefore their load could be. 2tp * 20 fr/s * 155 bit/fr * 4µs/bit = 0.0248 → = 2.48% extra load (in still mode). [8]

The error messages load on the bus would be neglected in calculation, error messages are initiated when one node in the bus discovers an error in the incoming message, because of bit error rate BER in CAN bus is equal to $3*10^{-11}$, which could be approximated to zero [13].

Messages with a sporadic nature, such as request messages (which are not allowed at all in the Scania red bus) would be also neglected in the busload calculations, due to the fact that their load is approximated to zero [9]

CHAPTER 4. FLOWCHART OF TOOL FUNCTIONS

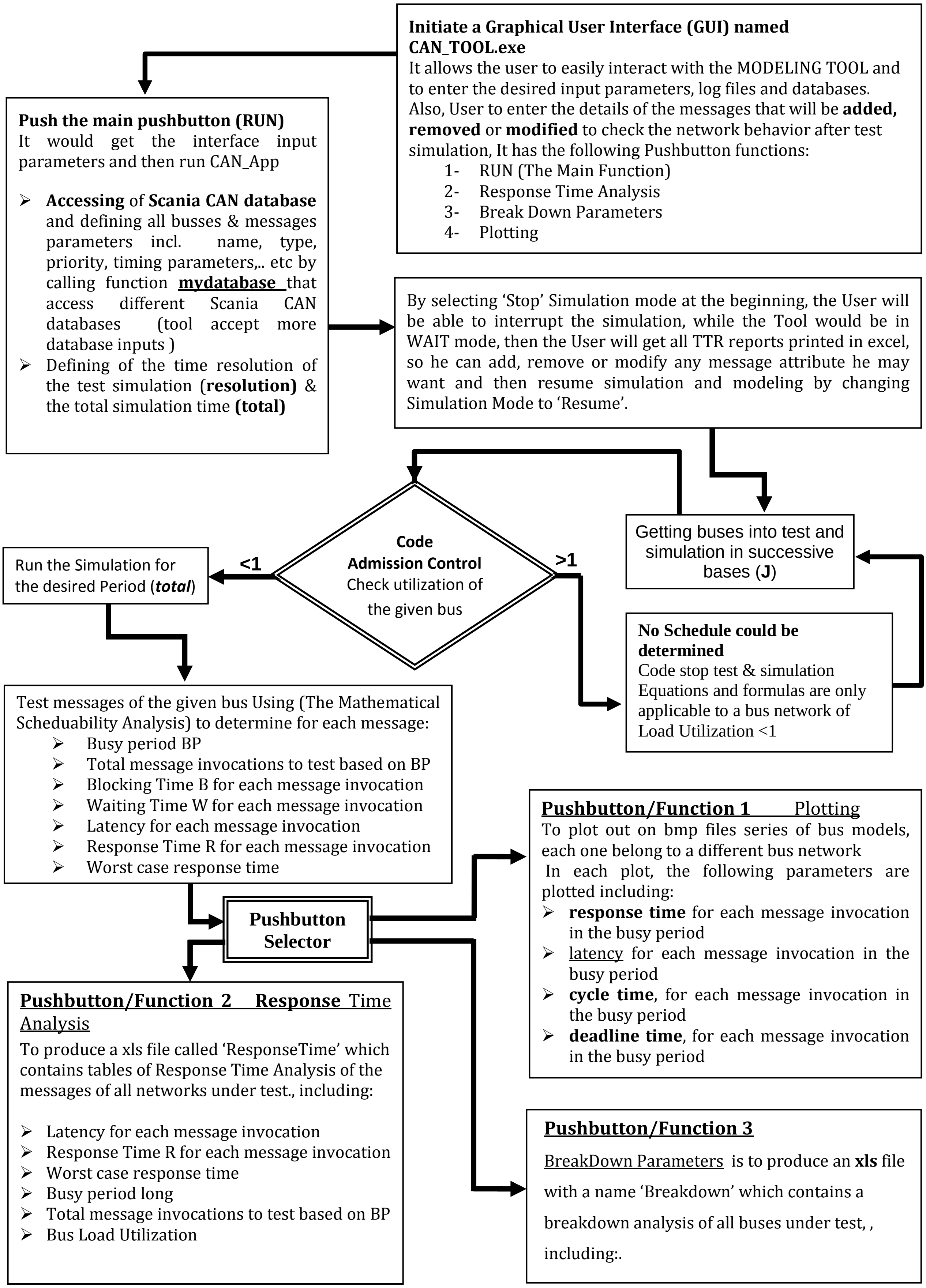


Figure 8 Flowchart of CAN Tool code to model bus load on CAN

CHAPTER 5. GRAPHICAL USER INTERFACE GUI

I chose to use a Graphical User Interface as a *human-CAN_Tool interface* (i.e., a way for humans to interact with computers) that uses *windows*, *icons* and *menus* and which can be manipulated by a mouse. [15]

5.1 THE TOOL'S INPUT

The Interface is stimulated with 28 inputs which varies from bit rate to message parameter to file names, including three panels for adding, removing or modifying a specific message or bench of messages.

The input consists of:

1- Data Log File is a log file that resulted from testing with CANalyzer that contains all possible CAN message logs in the network during the period of test and it should be in xlsx file format.

Very small Input Sample of data logs

Time	Bus	Message ID
0.000000	1	CF00400x
0.000272	1	8FE6E0Bx
0.000284	3	CFE5A27x
0.000274	1	CFE6CEEx
0.000282	2	CFF8100x
0.004805	1	18FE592Fx
0.000484	1	18E520C8x
0.000352	3	18FEC4C8x
0.000364	1	18FEC6C8x
0.000906	2	CF00203x
0.000286	1	C040B03x
0.001720	2	CFFA700x
0.000758	1	CFF8027x
0.000280	1	C040B11x
0.000276	1	18F0090Bx
0.006184	3	CF00203x
0.000282	1	18FFA103x
0.002102	2	CFE6CEEx
0.000282	3	CF00400x
0.000272	3	8FE6E0Bx
0.000270	1	CFF9111x
0.000286	2	18E4A827x
0.000290	3	18FECA00x

2- Diagnostic Log File is a log file that resulted from testing with CANalyzer while initiating of all possible diagnostic functions, it should be in xlsx file format.

3- Network Database file is a database file that contains all possible CAN messages along with its name, attribute, ID, source node, arbitration field and message type and transmitter ECU, this file is come in xls format.

4- The simulation mode allows User to interrupt the simulation, while the Tool will be on wait, then User will get all TTR reports printed in excel on newly created folder, so he can add, remove or modify any message attribute he may want and then resumes simulation and modeling by changing Simulation Mode to 'Resume Mode' in the main tool's dashboard.

5- Network Baud rate is a Popupmenus to select a baud rate of a specific network.

5.2 THE TOOL'S OUTPUT

Refer to figure 9 of the CAN TOOL Interface, there are seven pushbuttons in the Interface:

- The first (Main) pushbutton (RUN) to run the modeling and mathematical solution
- The second pushbutton (Plotting) is to plot out the models for each bus on **bmp files**
- The third pushbutton (Breakdown Parameters) is to produce an **xls file** with a name 'Breakdown.xls' which contains a breakdown analysis of all tested buses.
- The forth pushbutton (Response Time Analysis) is to produce an **xls file** called 'ResponseTime.xls' which contains tables of Response Time Analysis of all message of each of the targeted bus networks.
- The fifth pushbutton (Help & Support), clicking on this pushbutton will show a list of topics to get help on each one by selecting with mouse.
- The sixth pushbutton (Delete O/P) is to delete the produced excel TTR xls files & Breakdown/response time analysis txt files.
- The seventh pushbutton (Contact), clicking on this pushbutton will show contact details of the producer.

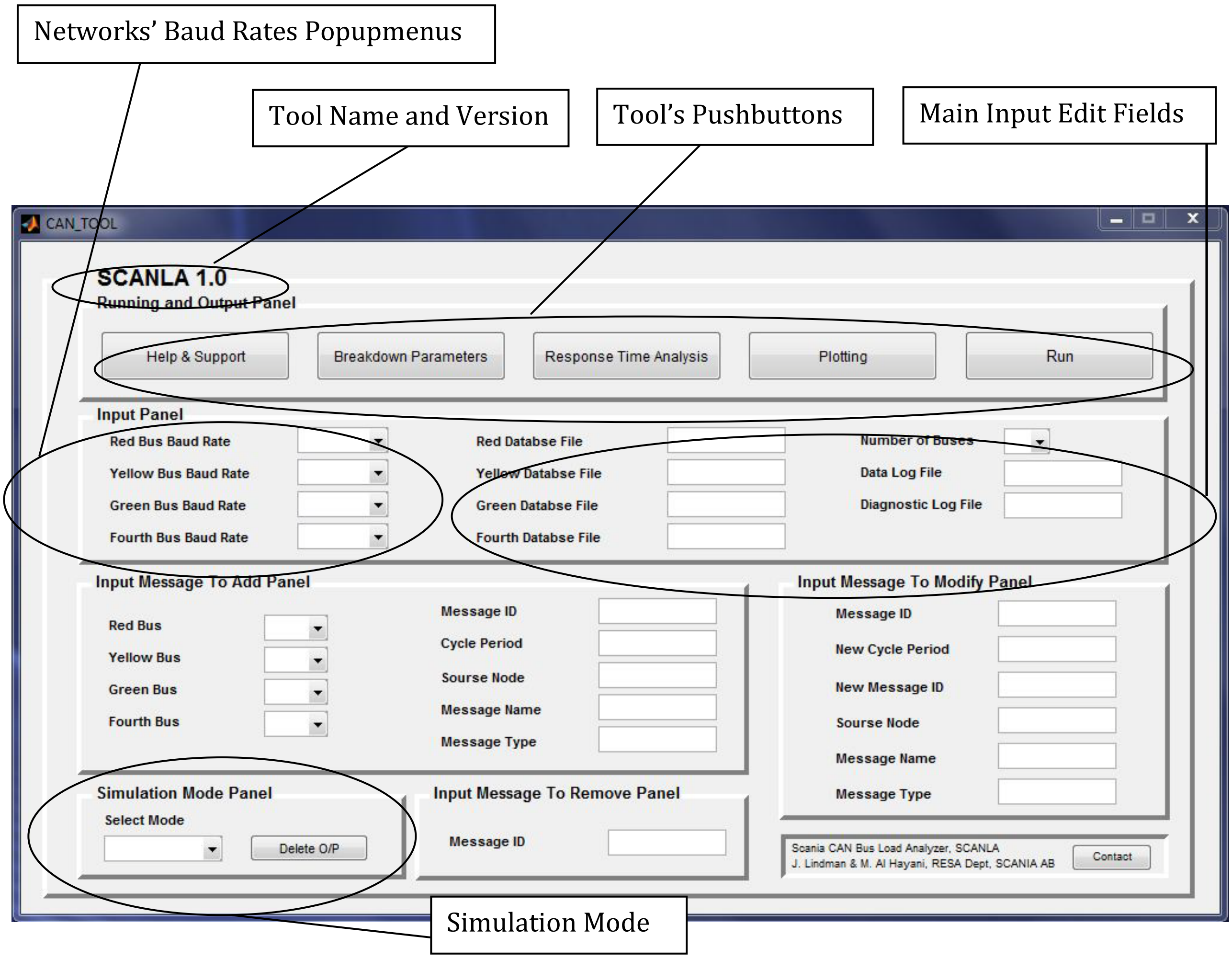


Figure 9 Snapshot of the Produced Human –CAN_TOOL Interface using of GUI

The developed CAN busload modeling tool) is running from executable application and could be installed on different computers direct from one single .exe application file.

It is able to map different CAN bus log files that resulted of testing with CANalyzer, such that the tool is digging deep into those log files and searches all possible data inside them to locate and analyze all messages, even if those log files contained hundreds of thousands of messages logs

Also it is able to access Scania CAN database and define all busses & messages parameters including name, type, priority, timing parameters, Etc.

EEC1_E	CF00400	Engine_E	6	20	Cyclic
HighResol	8FE6E0B	Brake_A	1	20	Cyclic
ASC1_K	CFE5A27	Coordinat	7	100	Cyclic
TCO1_TCC	CFE6CEE	Tachograp	8	20	Cyclic
DLN2_E	CFF8100	Engine_E	11	100	Cyclic
ASC3_F	18FE592F	GW_F	47	100	Cyclic
RGE21	18E520C8	Coordinat	32	100	Cyclic
EBS22_C8	18FEC4C8	GW_C8	51	100	Cyclic
EBS23_C8	18FEC6C8	GW_C8	52	100	Cyclic
ETC1_T	CF00203	Gearbox_	4	10	Cyclic
XBR_T_A	C040B03	Gearbox_	2	20	IfActive
EngineTor	CFFA700	Engine_E	15	20	Cyclic
DLN1_K	CFF8027	Coordinat	10	20	Cyclic
XBR_CCM_	C040B11	Coordinat	3	20	IfActive
VDC2_A	18F0090B	Brake_A	42	20	Cyclic
Transmiss	18FFA103	Gearbox_	78	100	Cyclic

Figure 10 Sample of the red bus traffic report.
(Produced by the tool)

Figure 10 is built by analyzing data log file and mapped to CAN red database file and contains message name, message ID, source node, relative priority, cycle time and message type. Note that these reports could be modified by the user to build a simulation that matches his own desire.

MessageName	MessageID	SourceNode	RelativePı	Bus	Cycle	Deadline	Execution	Response	BusyPerio	TotalInvo	Invocatior	Latency	WorstCas	BusLoadUtilisation
HighResolution	8FE6E0B	Brake_A	1	RedBus	20	20	0.31	0.62	0.62	1	1	0	0.62	33.8644
XBR_T_A	C040B03	Gearbox_T	2	RedBus	20	20	0.31	0.93	0.93	1	1	0	0.93	33.8644
XBR_CCM_A	C040B11	Coordinator_	3	RedBus	20	20	0.31	1.24	1.24	1	1	0	1.24	33.8644
ETC1_T	CF00203	Gearbox_T	4	RedBus	10	10	0.31	1.55	1.55	1	1	0	1.55	33.8644
EEC2_E	CF00300	Engine_E	5	RedBus	50	50	0.31	1.86	1.86	1	1	0	1.86	33.8644
EEC1_E	CF00400	Engine_E	6	RedBus	20	20	0.31	2.17	2.17	1	1	0	2.17	33.8644
ASC1_K	CFE5A27	Coordinator_	7	RedBus	100	100	0.31	2.48	2.48	1	1	0	2.48	33.8644
TCO1_TCO	CFE6CEE	Tachograph_T	8	RedBus	20	20	0.31	2.79	2.79	1	1	0	2.79	33.8644
EBC2Proprietar	CFF190B	Brake_A	9	RedBus	50	50	0.31	3.1	3.1	1	1	0	3.1	33.8644
DLN1_K	CFF8027	Coordinator_	10	RedBus	20	20	0.31	3.41	3.41	1	1	0	3.41	33.8644
DLN2_E	CFF8100	Engine_E	11	RedBus	100	100	0.31	3.72	3.72	1	1	0	3.72	33.8644
DLN6_K	CFF8927	Coordinator_	12	RedBus	1000	1000	0.31	4.03	4.03	1	1	0	4.03	33.8644
CCMSR_CCM	CFF9111	Coordinator_	13	RedBus	50	50	0.31	4.34	4.34	1	1	0	4.34	33.8644
RetarderPropri	CFFA210	Retarder_RD	14	RedBus	100	100	0.31	4.65	4.65	1	1	0	4.65	33.8644
EngineTorqueIr	CFFA700	Engine_E	15	RedBus	20	20	0.31	4.96	4.96	1	1	0	4.96	33.8644
CooGeneralInfc	CFFAF27	Coordinator_	16	RedBus	1000	1000	0.31	5.27	5.27	1	1	0	5.27	33.8644
CooGeneralInfc	CFFB027	Coordinator_	17	RedBus	200	200	0.31	5.58	5.58	1	1	0	5.58	33.8644
DIP_A	CFFB20B	Brake_A	18	RedBus	1000	1000	0.31	5.89	5.89	1	1	0	5.89	33.8644
KWP2000Phys	18DAFEFE	-- No Transmi	19	RedBus	50	50	0.31	6.2	6.2	1	1	0	6.2	33.8644
KWP2000Phys_	18DAFF00	Engine_E	20	RedBus	50	50	0.31	6.51	6.51	1	1	0	6.51	33.8644

Figure 11 Sample of the red bus response time analysis
(Produced by the tool)

Figure 11 is built by applying our mathematical solution to the data set of figure 10 in order to calculate response time analysis of those data set including busy period length, waiting time, blocking time response time and latency

BusName	BusSpeed_Kbits/s	BusUtilization	alpha	BreakdownUtilization
Red Bus	500	33.8644	1.5	50.7966
Yellow Bus	250	69.7004	0	0
Green Bus	250	36.89	1.2	44.268

Figure 12 Sample of the different networks' breakdown point (Produced by the tool)

Figure 12 is a showing the bus utilization of those networks tested in figure 10 and 11 and their respective breakdown utilization points.

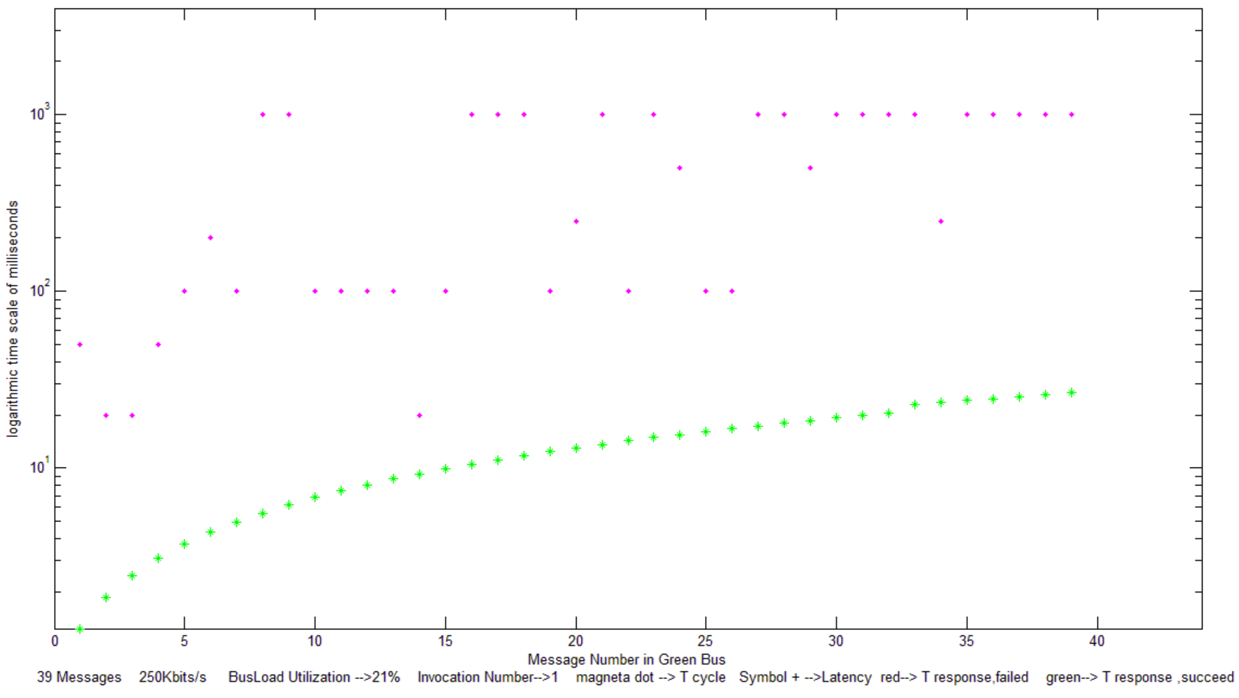


Figure 13 Sample of a green bus latency/response time plot (Produced by the tool)

Figure 13 shows plot of message response time and message latency in logarithmic scale of millimeters of each message invocations during busy period of those messages tested in figures 10, 11 and 12

CHAPTER 6. TEST RESULTS & ANALYSIS

The TTR BENCHMARK*, (based on* Scania T vehicle *LOG FILES done by CANalyzer test on March 22, 2012) is a report* describing a set of more than 200 messages of a specific Scania vehicle (Scania T vehicle) hardware configuration sent between multiple subsystems in three CAN bus networks (Red, Yellow and Green Scania CAN Buses) gatewayed with a powerful ECU known as the coordinator. Note that Scania deals with different combinations of those subsystems and associated messages.

There exist 19 subsystems equipped in the Scania T Vehicle as per the following:

Suspension Management System SMS, Brake Management System BMS, Gearbox Management System GMS, Engine Management System EMS, Articulation Control System ACS, All Wheel Drive System AWD, Locking and Alarm System LAS, Instrument Cluster System ICS, Visibility System VIS, Tachograph System TCS, Air Processing System APS, Body Wok System BWS, Body Chassis System BCS, Coordinator COO7, Crash Safety System CSS, Audio System AUS, Automatic Climate Control ACC, Air to Air Auxiliary Heater System ATA, Water to Air Auxiliary Heater System WTA, Clock and Timer System CTS, Road Transport Informatics System RTS, Road Transport Informatics Gateway RTG

The CAN networks connecting those ECU subsystems are required to handle more than 200 messages, some of them come with sporadic nature, while most are considered control data with fixed periodic nature and absolutely, the latency should be kept less than an associated period. While the sporadic messages do have an offline latency requirement that has been fixed prior to network setup, for instance all messages that are sent due to the driver interaction to get a latency requirement of 25ms[2], that would imply the response should show up to the driver immediately. Any given sporadic message should be given a period that represents a maximum inter arrival rate at the rate they may occur). [3]

Appendix 1 shows the TTR Benchmark tables of Scania T vehicle Red, Yellow and Green bus network (messages' requirements in order to get scheduled), those messages, some of them do have fixed periodic, but some do come sporadically in response to an external or internal event).

6.1 TEST 1, A REALISTIC TEST BASED ON CAN LOG FILE FROM T VEHICLE

The following TEST details the results of running our CAN TOOL resulting from analyzing data from the log file of *SCANIA T Vehicle*

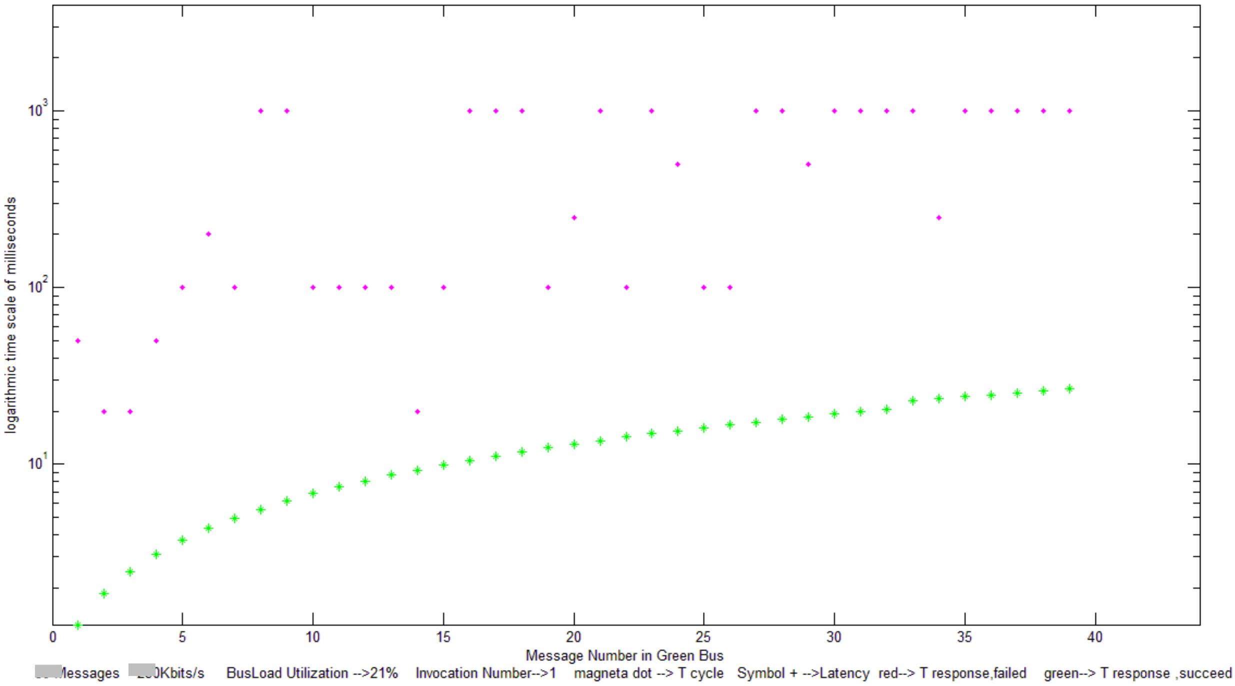


Figure 14 Response Time (Test1) of Green Bus Messages Invocation 1 (BP ends at 1st invocation)

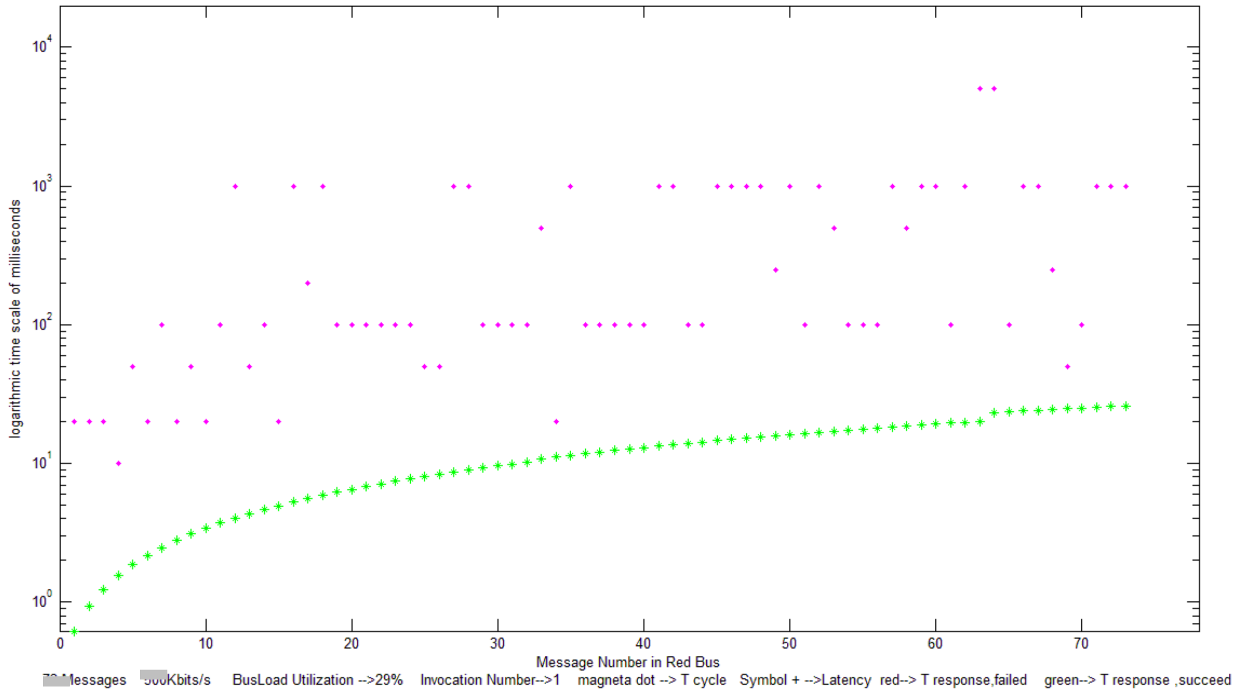


Figure 15 Response Time (Test1) of Red Bus Messages Invocation 1 (BP ends at 1st invocation)

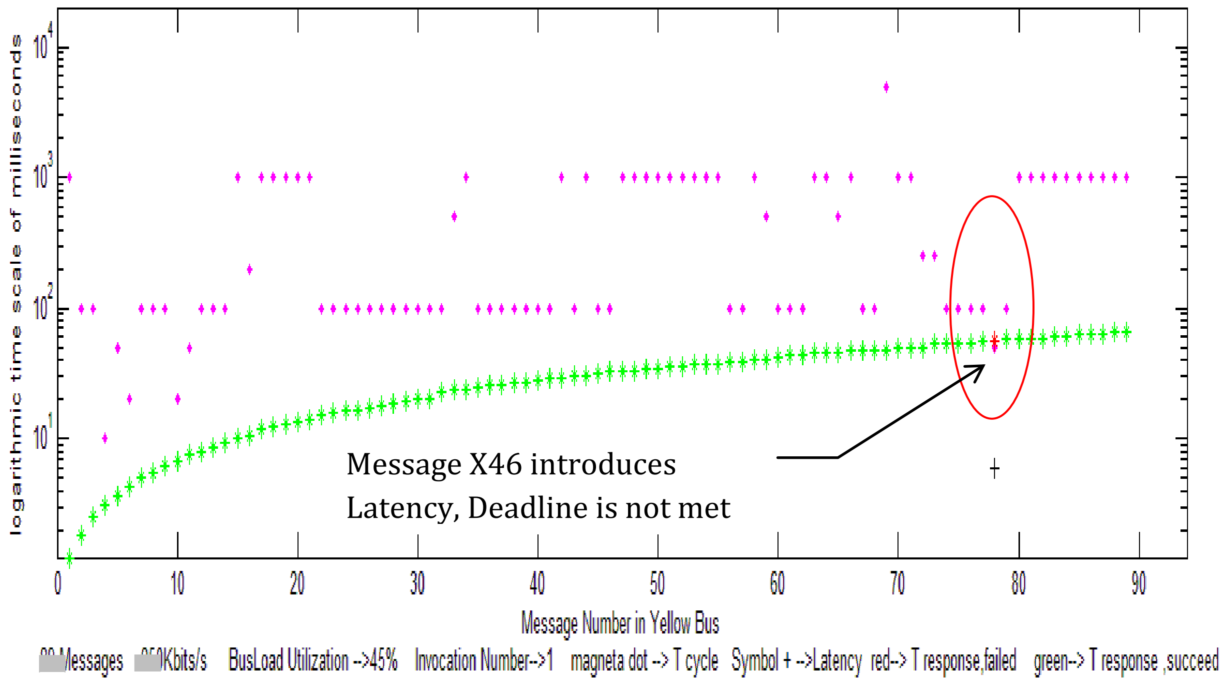


Figure 16 Response Time (Test1) of Yellow Bus Messages Invocation 1 (BP ends at 2nd invocation)

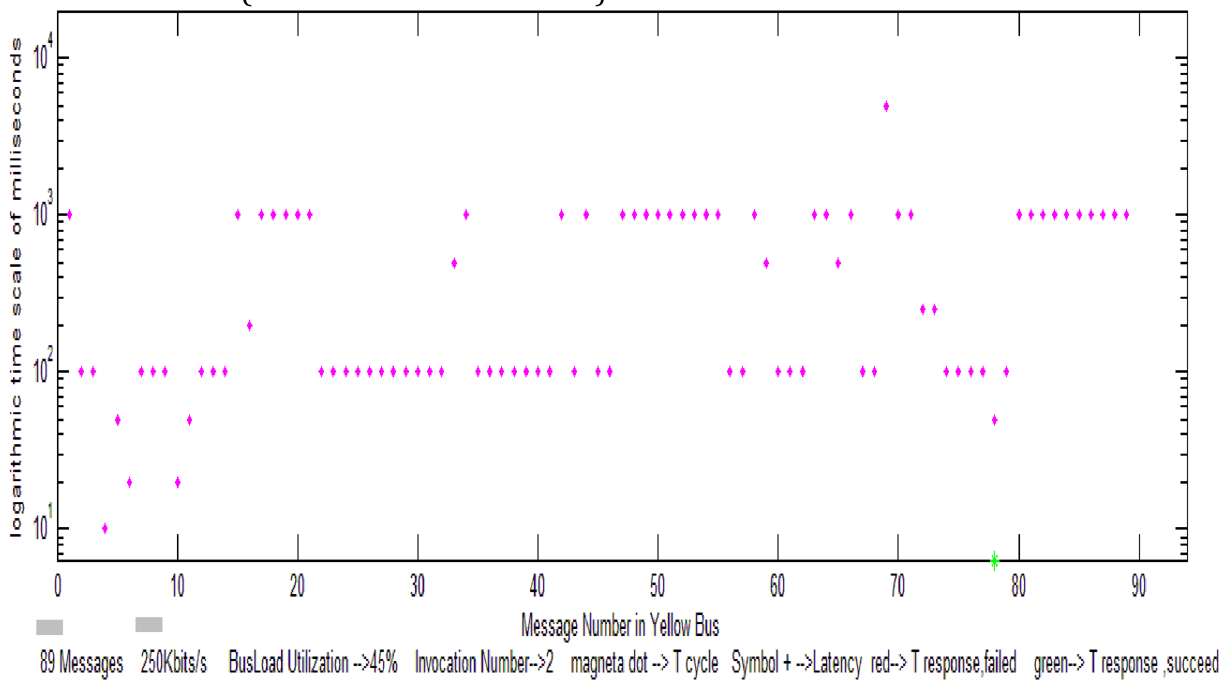


Figure 17 Response Time (Test1) of Yellow Bus Messages Invocation 2 (BP ends at 2nd invocation)

6.1.1 Resulted Breakdown Utilization & alpha

Bus	Bus Utilization	alpha	Breakdown Utilization
Red	34.29	1.50	51.4383
Yellow	46.62	0.00	00.0000
Green	20.71	2.20	45.5576

Table 2 Test1 Resulted Breakdown Utilization & alpha

Alpha does detail the breakdown utilization of the system for the given bus speed. While the **breakdown utilization** is the largest value of alpha such that when all the message periods are divided by alpha the system remains schedulable (i.e. all latency requirements are met).

It is an indication of how much slack there is in the system: a value of alpha close to but greater than 1 indicates that although the system is schedulable, there is little room for increasing the load. The 0 value for alpha for the bus speed indicates that no value for breakdown utilization can be found (an unschedulable system)

6.1.2 Encountered Latencies

In figure 12 of the Yellow bus response time plot, we have notice that the following message (refer to Appendix 1)

Message Name X46

Message ID 0x18FFXXXX

This Message does not meet deadline requirements and is not able to seize the bus in the desired cycle time, and it introduced latency.

Note: Message to control/send information to any type of GMS (AWD included)

6.1.3 Suggested Solution

Repairing the said network breakdown could be done by modifying either the cycle time (not preferred due to strict timing behavior of its signals) or modifying the message priority level (relatively preferred).

Message Name ‘X46’

Message ID 0x18FFXXXX

Raising the Priority of Message ‘X46’ → 0x0CFFXXXX

6.2 RUNNING TEST 2 ON THE REPAIRED YELLOW BUS

The following tables and charts resulted from rerunning the CAN TOOL with the new modified message X46 priority level in the yellow bus network

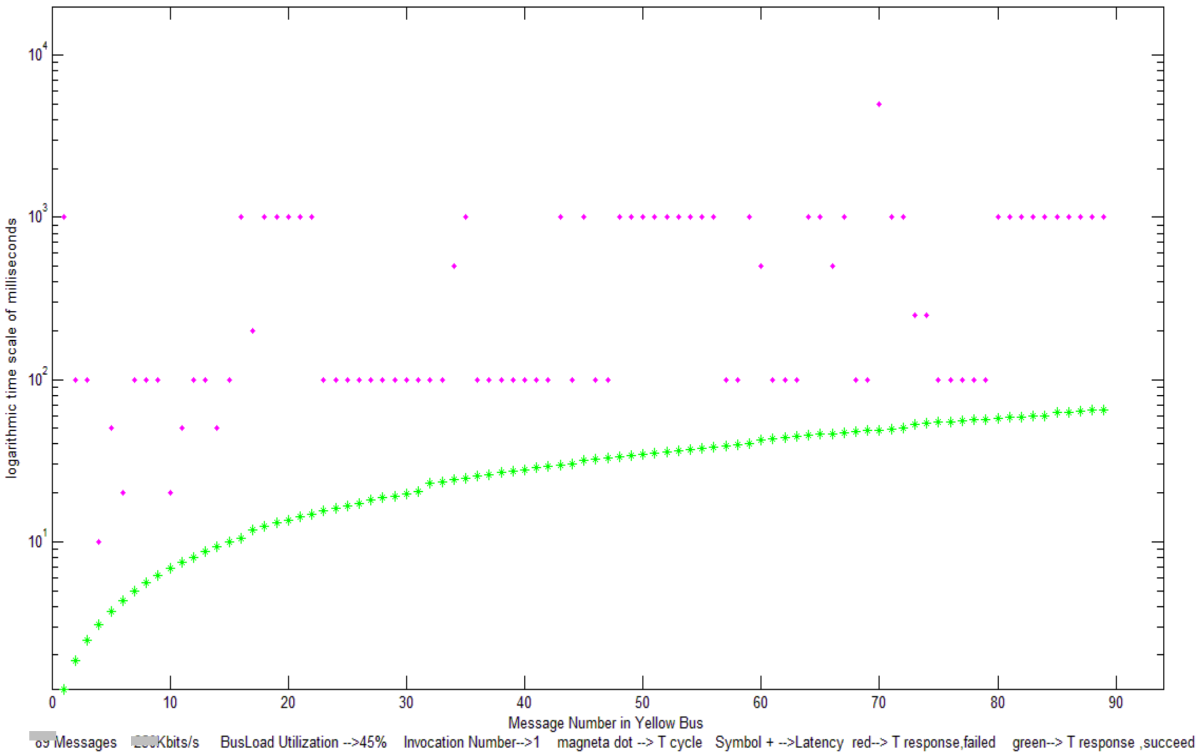


Figure 18 Response Time (Test2) of Yellow Bus Messages Invocation 1 (BP ends at 1st invocation)

6.2.1 Resulted Breakdown Utilization & alpha

Bus	Bus Utilization	alpha	Breakdown Utilization
Yellow	46.62	1.50	69.9360

Table 3 Test2 Resulted Breakdown Utilization & alpha

6.2.2 Discussion

We have seen in test 1 that although yellow bus utilization is relatively low, look at table 2 (about 46%), the breakdown utilization is reached and bus network starts to introduce latency, using the tool enabled us to visualize and locate the reason behind that breakdown, it is a critical real time message called X46 which has a fast cycle and a relative low priority.

The tool was helpful in repairing the said network breakdown, by modifying either the cycle time (not preferred due to strict timing behavior of its signals) or modifying the message priority level (relatively preferred).

6.3 REFERENCE TEST

The following Test details the results of running the CAN TOOL by stimulating with all possible messages of *SCANIA T Vehicle* into RED BUS with a lower to half bus bit rate.

Note: *The purpose of this test is to visualize the response time of red bus messages when the bit rate decreased to the half of its value, the response time in this case would be one more piece of evidence of how far the network is from the breakdown point.*

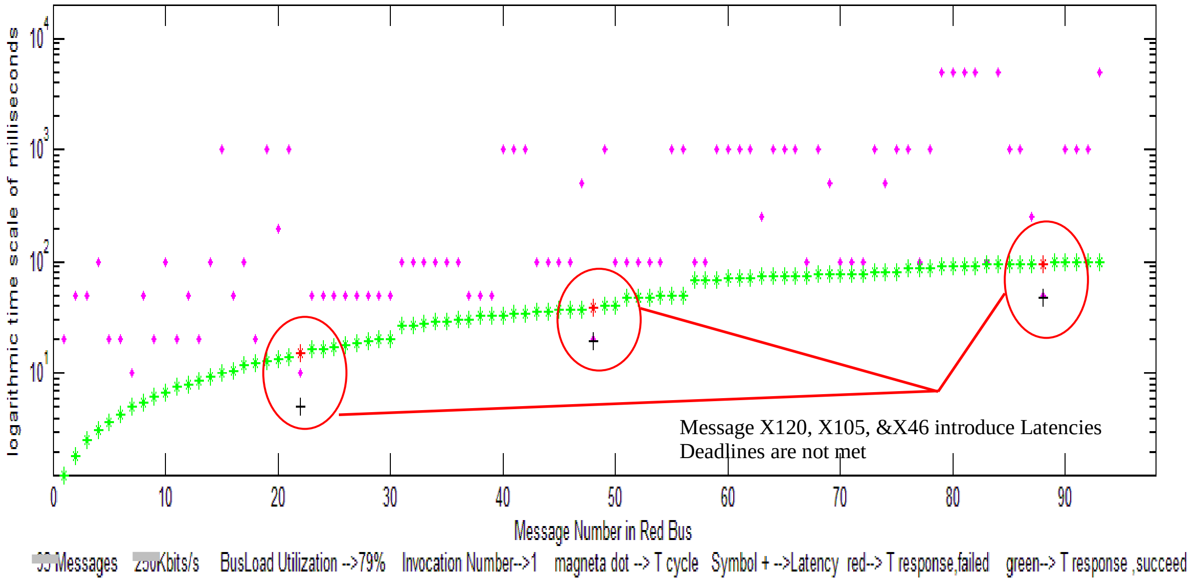


Figure 19 Response Time (Ref. Test) of Red Bus Messages Invocation 1 (BP ends at 2nd invocation)

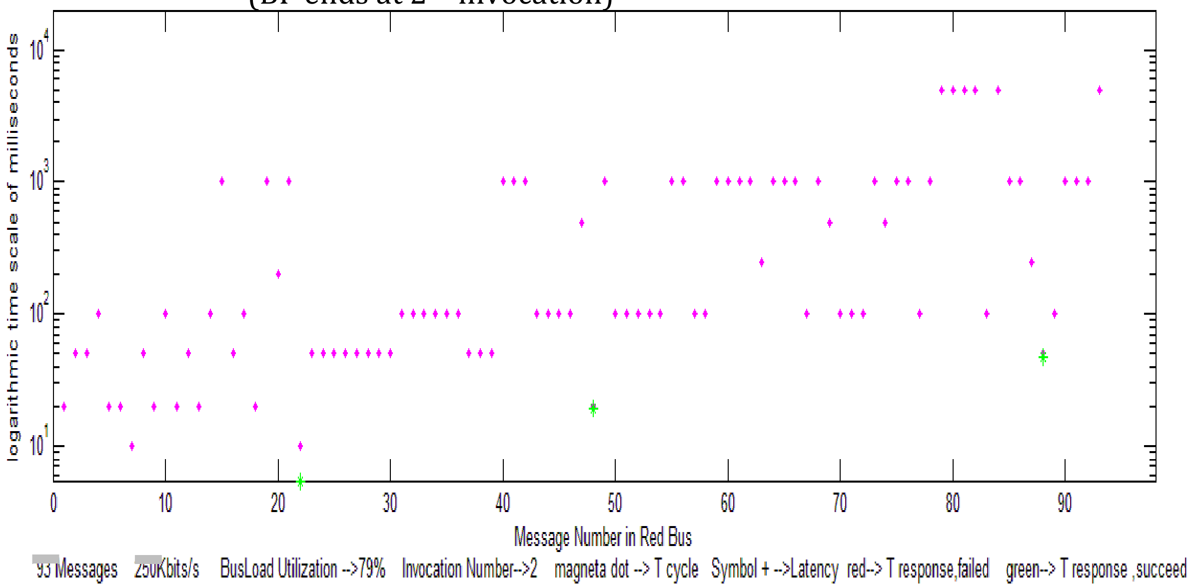


Figure 20 Response Time (Ref. Test) of Red Bus Messages Invocation 2 (BP ends at 2nd invocation)

6.3.1 Resulted Breakdown Utilization & alpha

Bus	Bus Utilization	alpha	Breakdown Utilization
Red	68.58%	0.0	00.00

Table 4 Ref. Test Resulted Breakdown Utilization & alpha

In figure 15, the following 3 messages have showed up latencies and deadline requirements aren't met

Message (1) Name	**X120**
Message ID	CFFXXXX

6 signals embedded in the message get delayed

Message (2) Name	**X105**
Message ID	18F0XXXX

6 signals embedded in the message get delayed

Message (3) Name	**X46**
Message ID	18FFXXXX

22 signals embedded in the message get delayed

6.3.2 Test Inferences

The Inferences of this test are showing how the bus network would behave in the case of reduction of its bit rate to the half value (table 4 and figure 15), in other words, it is showing which messages are most critical with respect to the introduction of latencies (the tool is producing complete tables of response time analysis for all messages and bus networks).

The test helps to focus on those failed messages to try to modify their priority level in a way to prevent red bus network from falling into breakdown.

CHAPTER 7. MODELING OF DIAGNOSTIC LOAD

7.1 MODELING OF KWP2000 DIAGNOSTIC MESSAGES LOAD

For KWP2000, The ISO-15765-2 Transport Protocol diagnostic messages, we are locating a server cycle to each diagnostic message ID, however it is still difficult to calculate their exact load because it depends on how many servers do we intend to initiate at a time and also how many commands will we activate at that time. [8]

In reality, a minimum of two servers are initiated at a time, which are sending multi packet messages with transport protocol [14], and therefore their load could be:

2tp * 20 fr/s * 155 bit/fr * 4µs/bit = 0.0248 → = 2.48% extra load.

For a worst case scenario, there is a maximum of eight servers in the red bus, twenty servers in the yellow bus and thirteen servers in the green bus, initiated at the same time, which are sending multi packet messages with transport protocol and therefore their load could be modeled as below.:

Worst case extra load on red bus

8tp * 20 fr/s * 155 bit/fr * 2µs/bit = 0.0496

→ = 4.96%

Worst case extra load on yellow bus

20tp * 20 fr/s * 155 bit/fr * 4µs/bit = 0.248

→ = 24.8%

Worst case extra load on green bus

13tp * 20 fr/s * 155 bit/fr * 4µs/bit = 0.1612

→ = 16.12%

7.2 RESPONSE TIME ANALYSIS WHEN INITIATING WORST CASE SCENARIO, WITH KWP2000 SERVERS

The following TEST details the results of running the CAN TOOL by stimulating with all possible messages of SCANIA T Vehicle with worst case diagnostics load.

The purpose of this test is to visualize the response time of CAN messages when a lot of diagnostic messages/commands have been initiated, the response time in this case would give us better understanding of how the far network is from breakdown point, when the vehicle is under diagnostic.

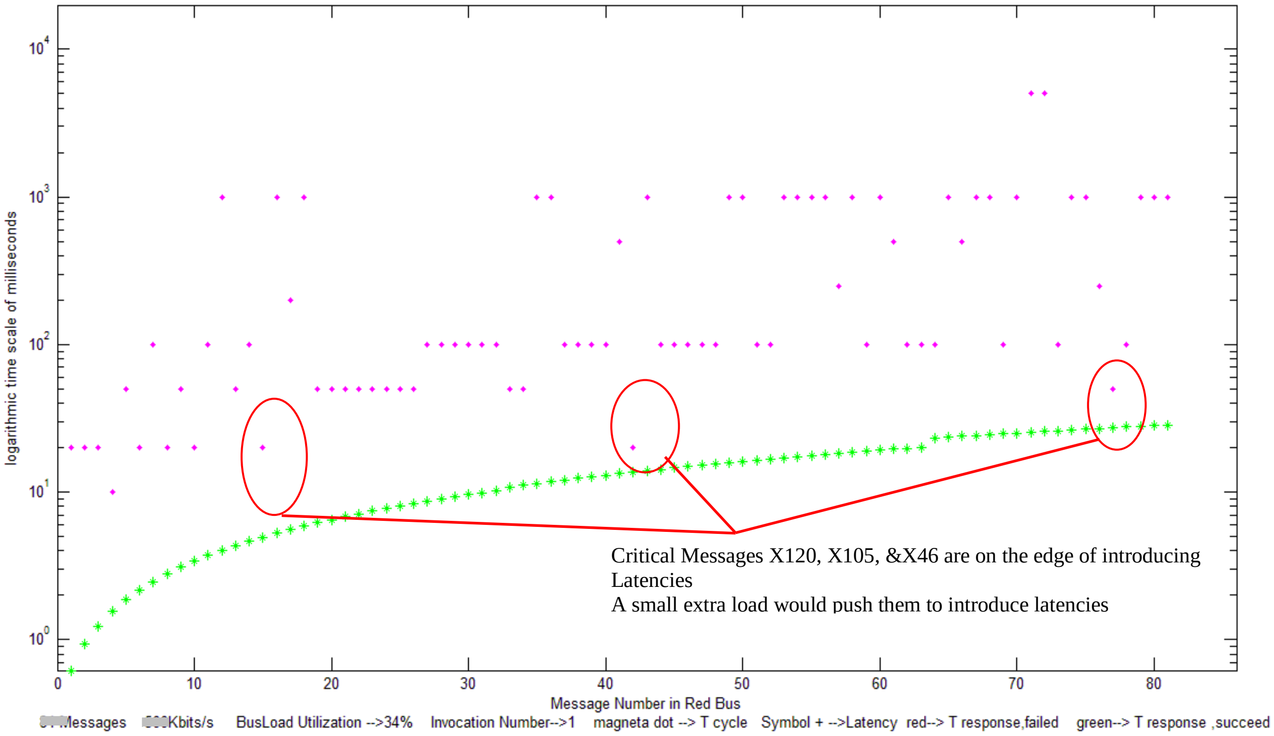


Figure 21 Response Time (Diagnostic Test) of Red Bus Messages Invocation 1 (BP ends at 1st invocation)

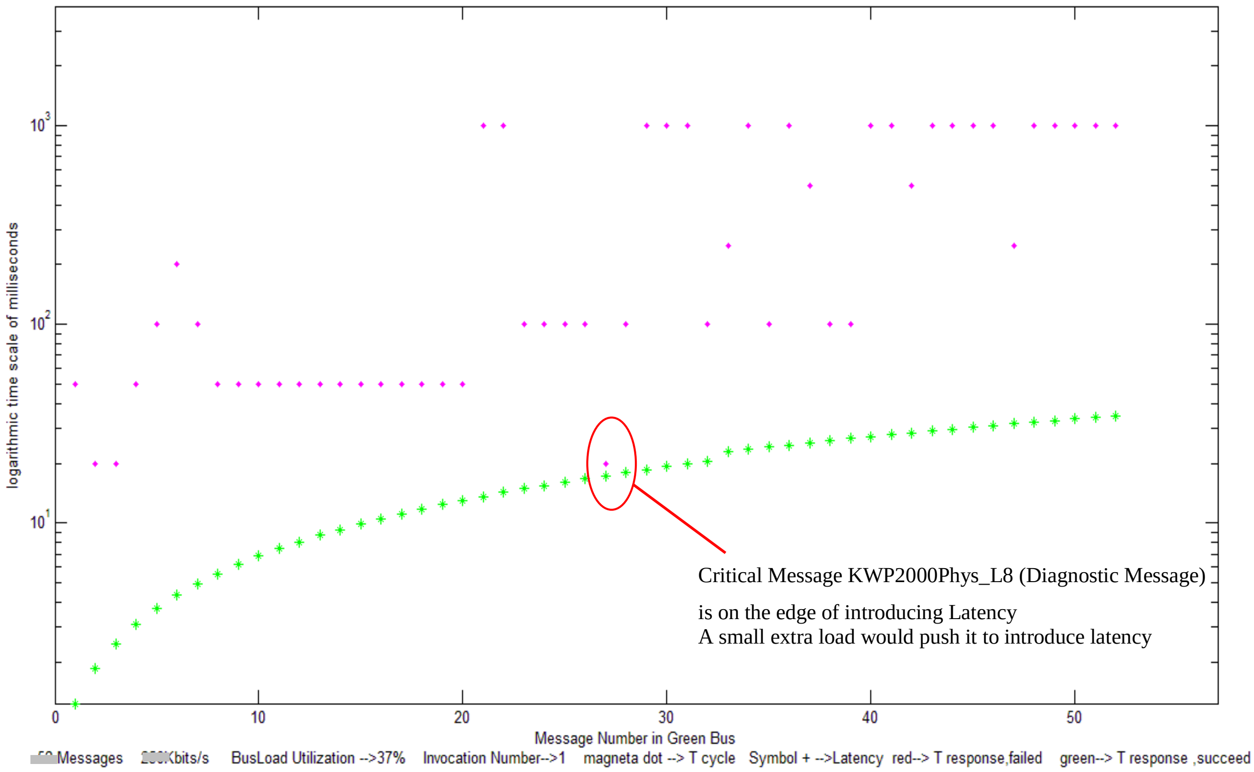


Figure 22 Response Time (Diagnostic Test) of Green Bus Messages Invocation 1 (BP ends at 1st invocation)

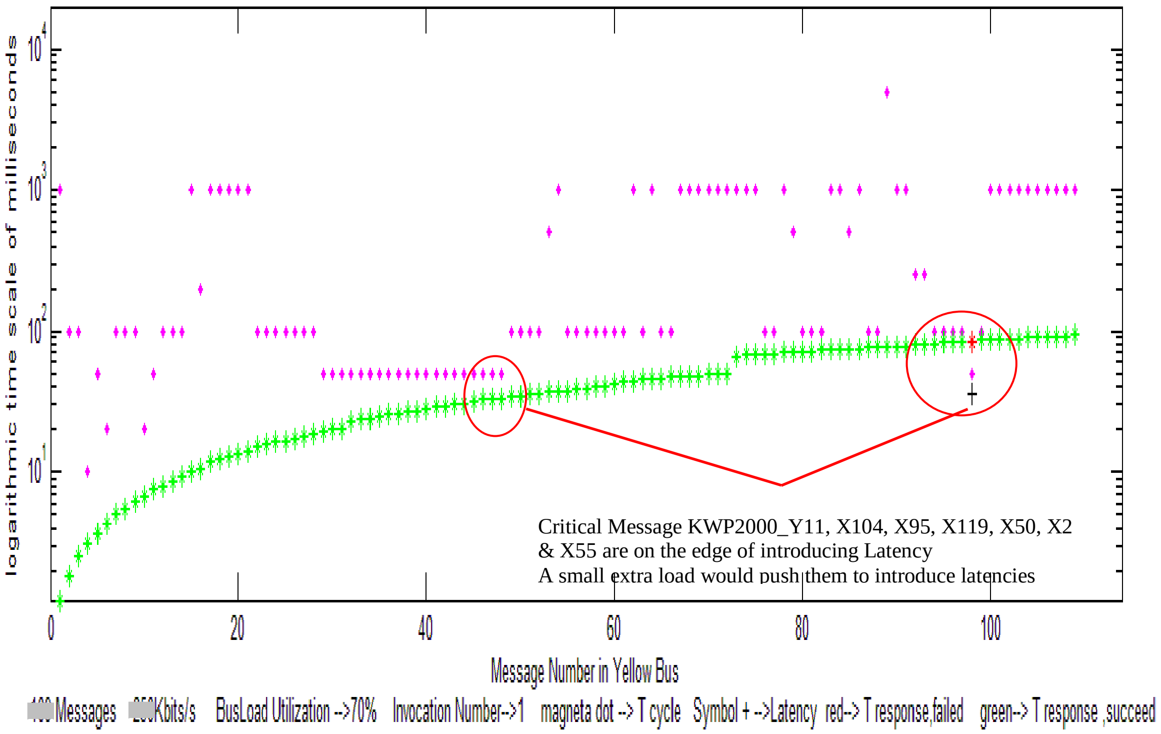


Figure 23 Response Time (Diagnostic Test) of Yellow Bus Messages Invocation 1 (BP ends at 2nd invocation)

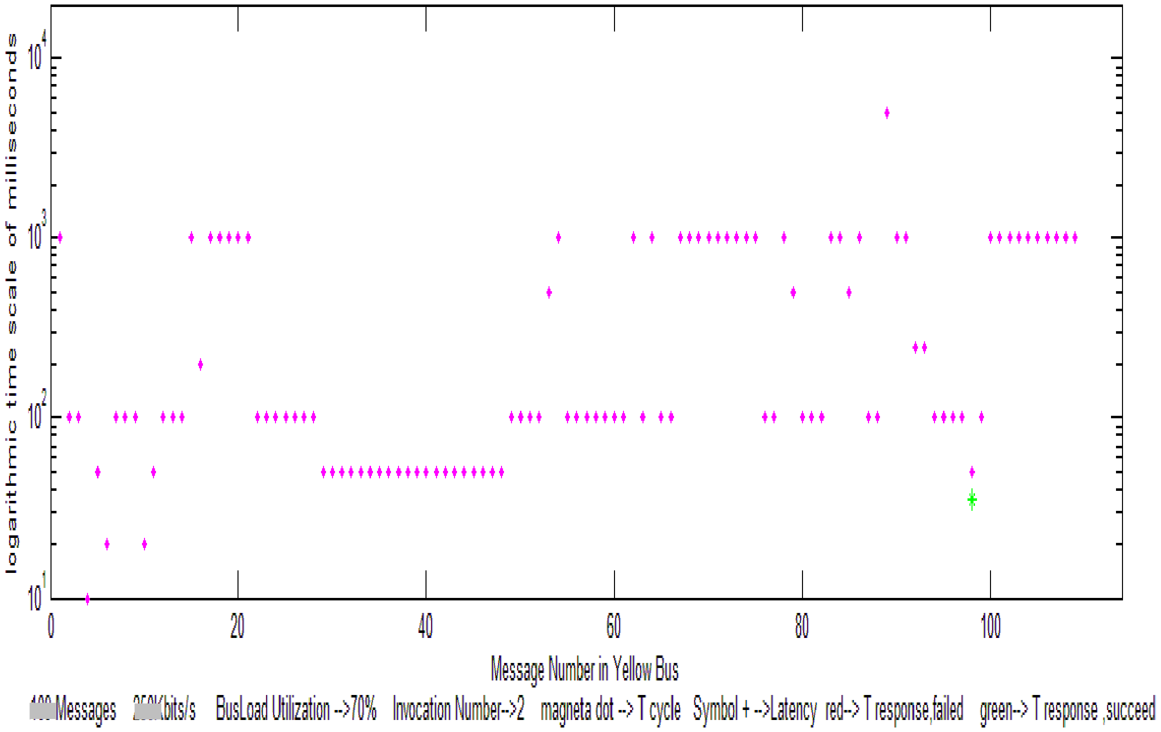


Figure 24 Response Time (Diagnostic Test) of Yellow Bus Messages Invocation 2 (BP ends at 2nd invocation)

7.2.1 Resulted Breakdown Utilization & alpha of diagnostic Test

Bus	Bus Utilization	alpha	Breakdown Utilization
Red	39.25	1.30	51.0279
Yellow	71.42	0.00	0.0000
Green	36.89	1.20	44.2680

Table 5 Ddiagnostic Test, Resulted Breakdown Utilization & alpha

7.2.2 Discussion

Green Bus Response

We found out (figure 18 and table 5) that the following diagnostic message is on the edge of introducing Latency; a small extra load would push it to introduce latency, refer to alpha value in table5 which is closed to 1.

- **Message (1) Name** KWP2000Phys_L8 (Diagnostic Message)

  Message ID 18DAXXXX

Yellow Bus Response

We found out (figure 19 & 20 and table 5) that the following 7 messages are on the edge of introducing Latency; a small extra load would push them to introduce latencies.

Also, the X46 would introduce much more latency than in TSET1

- **Message Name** X46

  Message ID 18FFXXXX

Those seven messages are:

- **Message (1) Name** **KWP2000_Y11** (Diagnostic Message)

  Message ID 18DBXXXX
- **Message (2) Name** X104

  Message ID 18EBXXXX
- **Message (3) Name** X95

  Message ID 18FFXXXX
- **Message (4) Name** **X119**

  Message ID 18FFXXXX
- **Message (5) Name** **X50**

Message ID 18FFXXXX

- **Message (6) Name** **X2**

  Message ID 18FFXXXX

- **Message (7) Name** **X55**

  Message ID 18FFXXXX

Red Bus Response

We found out (figure 17 and table 5) that the following 3 messages are on the edge of introducing Latency, A small extra load would push them to introduce latencies

- **Message (1) Name** X120

  Message ID CFFXXXX

- **Message (2) Name** X105

  Message ID 18F0XXXX

- **Message (3) Name** X46

  Message ID 18FFXXXX

7.2.3 Inference

The test helped us locate 11 messages that are at risk of introducing latencies (look at figures 17, 18 & 19) in the case of a light load added to the network (resulting in alpha value closed to 1 as in table5 and compare with table2), a good way to translate this conclusion in reality is by modifying the priority level of those 11 messages so that they will be located far away from that critical edge.

CHAPTER 8. CONCLUSIONS

The CAN Tool developed in this thesis which run as an executable application and based on MATLAB programming environment proved its ability to model busload for all possible Scania bus networks, ECU and messages combinations (by showing identical results with another results measured by SCANIA Test Department).

The Tool achieved modeling and visualizing messages latencies for each message invocation during the whole of a busy period.

The Tool is able to determine and predict based on mathematical calculation, breakdown points for any given CAN bus network along with some other breakdown parameters, actually the tool can run a simulation for a huge number of messages and for multiple buses on a parallel basis.

The CAN tool is able to access Scania CAN databases to define the whole buses and messages attributes and parameters, and avoiding stimulating them manually in order to keep the whole thing running automatically.

The CAN Tool is built with Graphical User Interface as a *human-computer interface*. A major advantage of GUIs is that it makes computer operation more intuitive.

The CAN Tool is able to map different CAN bus log files a result of testing with CANalyzer, such that the tool is digging deep into those log files and searches all possible data inside them to locate and analyze all messages with their actual response time and IDs, even if those log files contained hundreds of thousands of messages logs, such as the one we used in Test1.

8.1 SUGGESTIONS TO FUTURE WORK

I consider the tool resulting from this thesis as a preliminary modeling towards future development of another tool to model multiple in-vehicle serial bus communication networks into one single *simulator* to monitor how each single traffic behaves in different combinations of vehicles, communication modes and traffic design parameters.

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APPENDIX A INSTRUCTIONS ON HOW TO USE SCANLA

(The developed can busload analyzer tool)

SCANLA is the name of the developed CAN busload analyzer tool which is run from an executable application and uses a Graphical User Interface as a *human-computer interface.*

This Tool is developed and hoped that it will be useful but without any warranty. For a description and instructions on how to use, read intensively this sheet.

1- STARTING APPLICATION

It could be started simply by double click on SCANLA.exe.

2- GETTING THE INPUT

The Interface is stimulated with 28 inputs which vary from bit rate to message parameter to file names, including three panels for adding, removing or modifying a specific message or bench of messages.

The input consists of:

1- Data Log File is a log file that resulted from testing with CANalyzer that contains all possible CAN message logs in the networks (CAN Messages IDs + Bus Number) during the period of test and it should be in xlsx file format.

2- Diagnostic Log File is a log file that resulted from testing with CANalyzer while initiating of all possible diagnostic functions, it should be in xlsx file format.

3- Network Database file is a database file that contains all possible CAN messages along with its name, attribute, ID, source node, arbitration field and message type and transmitter ECU, this file is come in xls format.

4- Network Baud rate is a Popupmenus to select a baud rate of a specific network.

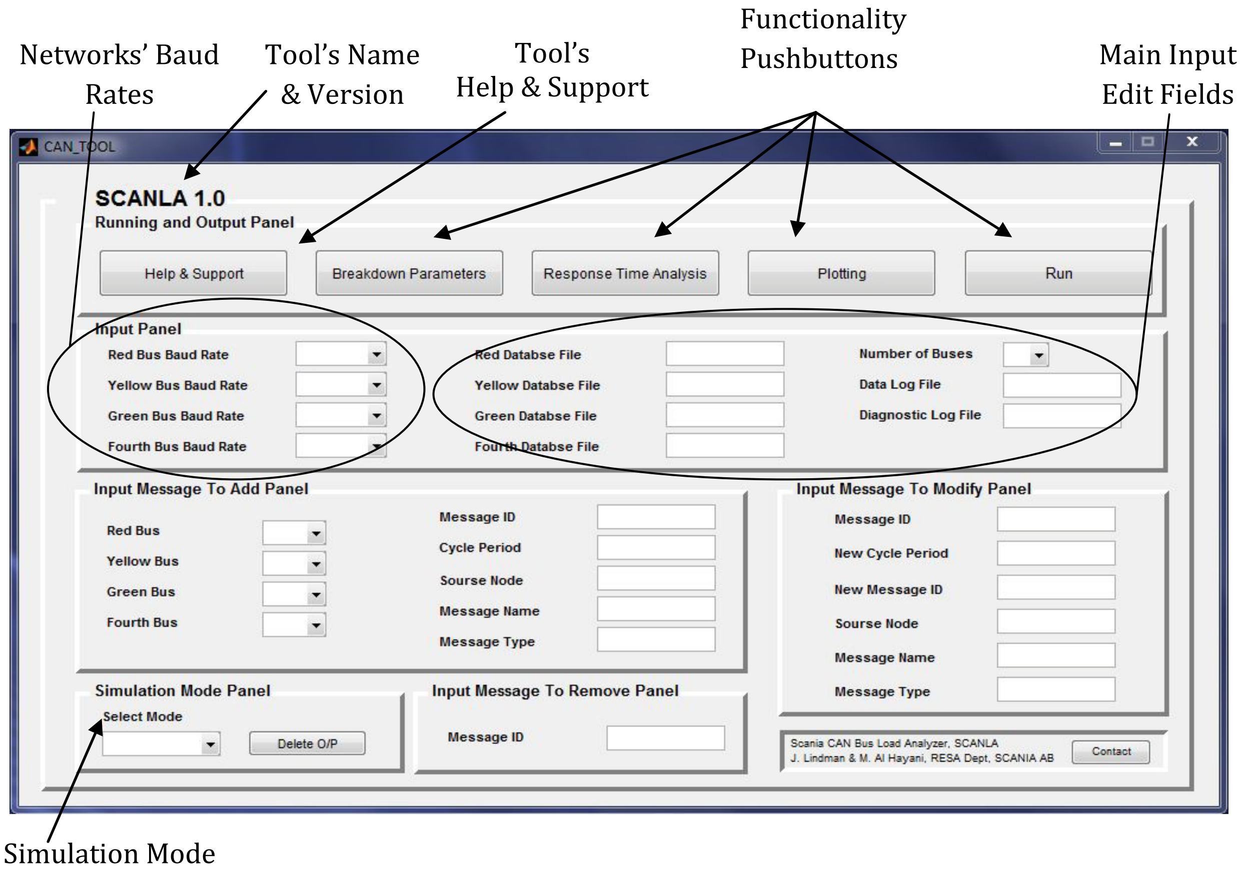
3- SELECTING THE SIMULATION MODE

Two simulation modes are allowed in the tool including:

1- RESUME mode will run the simulation without allowing any interruption during modeling
2- STOP mode allows User to interrupt the simulation, while the Tool will be on wait, then User will get all CAN TTR reports printed in excel on newly created folder, so he can add, remove or modify any message attribute he may want and then resumes simulation and modeling by changing Simulation Mode to 'Resume Mode' in the main tool's dashboard.

4- RUNNING THE ANALYSIS TOOL

This could be done easily by clicking on the 'RUN' pushbutton and only after finishing with steps 1 and 2.



Snapshot of SCANLA
The developed CAN busload analyzer

5- PRODUCING THE OUTPUT

Refer to tool's Interface figure; there are seven pushbuttons in the Interface:

- The first and main pushbutton (RUN) is to run the modeling and mathematical solution as the first stage of in our tool (second, third and fourth pushbuttons are only allowed after finishing with RUN).
- The second pushbutton (Plotting) is to plot out models for each bus on **bmp files**
- The third pushbutton (Breakdown Parameters) is to produce an **xls file** with a name 'Breakdown.xls' which contains a breakdown analysis of all tested buses.
- The forth pushbutton (Response Time Analysis) is to produce an **xls file** called 'ResponseTime.xls' which contains tables of Response Time Analysis of all message of each of the targeted bus networks.
- The fifth pushbutton (Help & Support), clicking on this pushbutton will show a list of topics to get help on each one by selecting with mouse.
- The sixth pushbutton (Delete O/P) is to delete the produced excel TTR xls files, Breakdown txt file, response time analysis txt file and the plot bmp files.
- The seventh pushbutton (Contact), clicking on this pushbutton will show contact details of the producers.

Note that for each simulation run, an automatic simulation **unique number and date** are stamped for archiving purpose.

SCANLA is the name of the developed CAN busload analyzer tool in this thesis which is running as an executable application and uses a Graphical User Interface as a *human-computer interface*.

Please let the producers of the mentioned tool know of any improvements, changes or modifications that might be made. <musab_alhidithy@yahoo.com>

APPENDIX B SCANIA T, CAN TRAFFIC TTR REPORTS

SCANIA T VEHICLE Red Bus Traffic

Message Name	Message ID	Cycle ms	Type
X126	8FEXXXX	20	Cyclic
X12	C00XXXX	50	IfActive
X19	C00XXXX	50	IfActive
X3	C00XXXX	100	IfActive
X74	C04XXXX	20	IfActive
X78	C04XXXX	20	IfActive
X18	CF0XXXX	10	Cyclic
X22	CF0XXXX	50	Cyclic
X31	CF0XXXX	20	Cyclic
X11	CFEXXXX	100	Cyclic
X44	CFEXXXX	20	Cyclic
X98	CFFXXXX	50	Cyclic
X38	CFFXXXX	20	Cyclic
X53	CFFXXXX	100	Cyclic
X70	CFFXXXX	1000	NoMsgSendType
X56	CFFXXXX	50	Cyclic
X84	CFFXXXX	100	Cyclic
X89	CFFXXXX	20	Cyclic
X5	CFFXXXX	1000	Cyclic
X1	CFFXXXX	200	Cyclic
X47	CFFXXXX	1000	Cyclic
X120	CFFXXXX	10	IfActive
X34	18E4XXXX	100	Cyclic
X60	18E4XXXX	100	Cyclic
X27	18E4XXXX	100	Cyclic
X121	18E4XXXX	100	Cyclic
X66	18E4XXXX	100	Cyclic
X41	18E5XXXX	100	Cyclic
X104	18EBXXXX	50	NoMsgSendType
X92	18EB XXXX	50	NoMsgSendType
X30	18EB XXXX	50	NoMsgSendType
X4	18EC XXXX	1000	IfActive
X118	18EC XXXX	1000	IfActive
X20	18EC XXXX	1000	IfActive
X15	18F0XXXX	100	Cyclic
X23	18F0 XXXX	100	Cyclic
X21	18F0XXXX	100	Cyclic
X68	18F0XXXX	100	Cyclic
X75	18F0XXXX	500	Cyclic
X105	18F0XXXX	20	Cyclic
X91	18FDXXXX	1000	Cyclic
X6	18FDXXXX	100	Cyclic
X24	18FEXXXX	100	Cyclic
X87	18FEXXXX	100	Cyclic
X16	18FE XXXX	100	Cyclic
X83	18FE XXXX	100	Cyclic
X93	18FE XXXX	1000	Cyclic
X94	18FE XXXX	1000	Cyclic
X8	18FE XXXX	100	Cyclic
X57	18FE XXXX	100	Cyclic
X35	18FEXXXX	1000	Cyclic
X88	18FE XXXX	1000	Cyclic
X61	18FE XXXX	1000	Cyclic
X9	18FE XXXX	1000	Cyclic
X42	18FEXXXX	250	Cyclic
X10	18FEXXXX	1000	Cyclic
X65	18FE XXXX	1000	Cyclic
X36	18FEXXXX	1000	Cyclic
X13	18FEXXXX	100	Cyclic
X103	18FEXXXX	1000	Cyclic
X101	18FEXXXX	500	Cyclic
X43	18FEXXXX	100	Cyclic
X96	18FE XXXX	100	Cyclic
X62	18FE XXXX	100	Cyclic
X14	18FE XXXX	1000	Cyclic
X79	18FEXXXX	500	Cyclic
X17	18FEXXXX	1000	Cyclic
X39	18FEXXXX	1000	Cyclic
X58	18FFXXXX	100	Cyclic
X25	18FFXXXX	1000	Cyclic
X45	18FFXXXX	5000	Cyclic
X100	18FFXXXX	5000	Cyclic
X51	18FFXXXX	5000	Cyclic
X102	18FFXXXX	5000	Cyclic
X26	18FFXXXX	100	Cyclic
X67	18FFXXXX	5000	Cyclic
X59	18FFXXXX	1000	Cyclic
X28	18FFXXXX	1000	Cyclic
X97	18FFXXXX	250	Cyclic
X46	18FFXXXX	50	Cyclic
X55	18FFXXXX	100	Cyclic
X29	18FFXXXX	1000	Cyclic
X32	18FFXXXX	1000	Cyclic
X48	18FFXXXX	1000	Cyclic
X64	1CFEXXXX	5000	Cyclic

SCANIA T VEHICLE Yellow Bus Traffic

Message Name	Message ID	Cycle ms	Type
X40	FFXXXX	1000	Cyclic
X90	CD1XXXX	100	IfActive
X99	CD2XXXX	100	Cyclic
X18	CF0XXXX	10	Cyclic
X22	CF0XXXX	50	Cyclic
X31	CF0XXXX	20	Cyclic
X11	CFEXXXX	100	Cyclic
X52	CFEXXXX	100	Cyclic
X72	CFEXXXX	100	Cyclic
X44	CFEXXXX	20	Cyclic
X98	CFFXXXX	50	Cyclic
X33	CFFXXXX	100	Cyclic
X53	CFFXXXX	100	Cyclic
X84	CFFXXXX	100	Cyclic
X5	CFFXXXX	1000	Cyclic
X1	CFFXXXX	200	Cyclic
X47	CFFXXXX	1000	Cyclic
X80	CFFXXXX	1000	Cyclic
X37	CFFXXXX	1000	Cyclic
X76	CFFXXXX	1000	Cyclic
X54	CFFXXXX	1000	Cyclic
X86	CFFXXXX	100	Cyclic
X63	CFFXXXX	100	Cyclic
X77	CFFXXXX	100	Cyclic
X85	CFFXXXX	100	Cyclic
X82	10FFXXXX	100	Cyclic
X69	10FFXXXX	100	Cyclic
X71	18D0XXXX	100	Cyclic
X41	18E5XXXX	100	Cyclic
X104	18FBXXXX	50	NoMsgSendType
X4	18ECXXXX	1000	IfActive
X15	18F0XXXX	100	Cyclic
X21	18F0XXXX	100	Cyclic
X68	18F0XXXX	100	Cyclic
X75	18F0XXXX	500	Cyclic
X91	18FDXXXX	1000	Cyclic
X6	18FDXXXX	100	Cyclic
X24	18FEXXXX	100	Cyclic
X87	18FEXXXX	100	Cyclic
X73	18FEXXXX	100	Cyclic
X106	18FEXXXX	100	Cyclic
X16	18FEXXXX	100	Cyclic
X83	18FEXXXX	100	Cyclic
X93	18FEXXXX	1000	Cyclic
X109	18FEXXXX	100	Cyclic
X94	18FEXXXX	1000	Cyclic
X8	18FEXXXX	100	Cyclic
X57	18FEXXXX	100	Cyclic
X35	18FEXXXX	1000	Cyclic
X88	18FEXXXX	1000	Cyclic
X61	18FEXXXX	1000	Cyclic
X9	18FEXXXX	1000	Cyclic
X112	18FEXXXX	1000	Cyclic
X107	18FEXXXX	1000	Cyclic
X111	18FEXXXX	1000	Cyclic
X81	18FEXXXX	1000	Cyclic
X10	18FEXXXX	1000	Cyclic
X65	18FEXXXX	1000	Cyclic
X108	18FEXXXX	1000	Cyclic
X36	18FEXXXX	1000	Cyclic
X110	18FEXXXX	100	Cyclic
X13	18FEXXXX	100	Cyclic
X103	18FEXXXX	1000	Cyclic
X115	18FEXXXX	500	Cyclic
X43	18FEXXXX	100	Cyclic
X119	18FEXXXX	100	Cyclic
X62	18FEXXXX	100	Cyclic
X117	18FEXXXX	1000	Cyclic
X14	18FEXXXX	1000	Cyclic
X79	18FEXXXX	500	Cyclic
X39	18FEXXXX	1000	Cyclic
X58	18FFXXXX	100	Cyclic
X115	18FFXXXX	100	Cyclic
X45	18FFXXXX	5000	Cyclic
X118	18FFXXXX	5000	Cyclic
X114	18FFXXXX	5000	Cyclic
X116	18FFXXXX	5000	Cyclic
X59	18FFXXXX	1000	Cyclic
X28	18FFXXXX	1000	Cyclic
X97	18FFXXXX	250	Cyclic
X117	18FFXXXX	250	Cyclic
X95	18FFXXXX	100	Cyclic
X119	18FFXXXX	100	Cyclic
X50	18FFXXXX	100	Cyclic
X2	18FFXXXX	100	Cyclic
X46	18FFXXXX	50	Cyclic
X55	18FFXXXX	100	Cyclic
X29	18FFXXXX	1000	Cyclic
X122	18FFXXXX	1000	Cyclic

X32	18FFXXXX	1000	Cyclic
X123	18FFXXXX	1000	Cyclic
X129	18FFXXXX	1000	Cyclic
X124	18FFXXXX	1000	Cyclic
X48	18FFXXXX	1000	Cyclic
X128	18FFXXXX	1000	Cyclic
X125	1CDEXXXX	1000	Cyclic
X64	1CFEXXXX	5000	Cyclic
X7	1CFFXXXX	1000	Cyclic
X127	1CFFXXXX	1000	Cyclic
X130	1CFFXXXX	1000	Cyclic
X137	1CFFXXXX	1000	Cyclic

SCANIA T VEHICLE Green Bus Traffic

Message Name	Message ID	Cycle ms	Type
X22	CF0XXXX	50	Cyclic
X31	CF0XXXX	20	Cyclic
X44	CFEXXXX	20	Cyclic
X98	CFFXXXX	50	Cyclic
X84	CFFXXXX	100	Cyclic
X1	CFFXXXX	200	Cyclic
X71	18D0XXXX	100	Cyclic
X133	18E0XXXX	1000	Cyclic
X136	18E0XXXX	1000	Cyclic
X15	18F0XXXX	100	Cyclic
X23	18F0XXXX	100	Cyclic
X21	18F0XXXX	100	Cyclic
X68	18F0XXXX	100	Cyclic
X105	18F0XXXX	20	Cyclic
X6	18FDXXXX	100	Cyclic
X132	18FDXXXX	1000	Cyclic
X93	18FEXXXX	1000	Cyclic
X94	18FEXXXX	1000	Cyclic
X57	18FEXXXX	100	Cyclic
X42	18FEXXXX	250	Cyclic
X36	18FEXXXX	1000	Cyclic
X110	18FEXXXX	100	Cyclic
X103	18FEXXXX	1000	Cyclic
X115	18FEXXXX	500	Cyclic
X43	18FEXXXX	100	Cyclic
X62	18FEXXXX	100	Cyclic
X135	18FEXXXX	1000	Cyclic
X14	18FEXXXX	1000	Cyclic
X79	18FEXXXX	500	Cyclic
X39	18FEXXXX	1000	Cyclic
X131	18FFXXXX	1000	Cyclic
X134	18FFXXXX	1000	Cyclic
X28	18FFXXXX	1000	Cyclic
X97	18FFXXXX	250	Cyclic
X122	18FFXXXX	1000	Cyclic
X32	18FFXXXX	1000	Cyclic
X123	18FFXXXX	1000	Cyclic
X129	18FFXXXX	1000	Cyclic

APPENDIX C SCANIA T, CAN RESSPONSE TIME ANALYSIS

TIMING ANALYSIS OF SCANIA T VEHICLE RED BUS

Message Name	Message ID	Cycle ms	Type	Total Message inv. During BP	Response Time R1 ms	Response Time R2 ms
X126	8FEXXXX	20	Cyclic	1	0,60	0
X12	C00XXXX	50	IfActive	1	0,90	0
X19	C00XXXX	50	IfActive	1	1,20	0
X3	C00XXXX	100	IfActive	1	1,60	0
X74	C04XXXX	20	IfActive	1	1,90	0
X78	C04XXXX	20	IfActive	1	2,20	0
X18	CF0XXXX	10	Cyclic	1	2,50	0
X22	CF0XXXX	50	Cyclic	1	2,80	0
X31	CF0XXXX	20	Cyclic	1	3,10	0
X11	CFEXXXX	100	Cyclic	1	3,40	0
X44	CFEXXXX	20	Cyclic	1	3,70	0
X98	CFFXXXX	50	Cyclic	1	4,00	0
X38	CFFXXXX	20	Cyclic	1	4,30	0
X53	CFFXXXX	100	Cyclic	1	4,60	0
X70	CFFXXXX	1000	NoMsgSendType	1	5,00	0
X56	CFFXXXX	50	Cyclic	1	5,30	0
X84	CFFXXXX	100	Cyclic	1	5,60	0
X89	CFFXXXX	20	Cyclic	1	5,90	0
X5	CFFXXXX	1000	Cyclic	1	6,20	0
X1	CFFXXXX	200	Cyclic	1	6,50	0
X47	CFFXXXX	1000	Cyclic	1	6,80	0
X120	CFFXXXX	10	IfActive	1	7,10	0
X34	18E4XXXX	100	Cyclic	1	7,40	0
X60	18E4XXXX	100	Cyclic	1	7,70	0
X27	18E4XXXX	100	Cyclic	1	8,10	0
X121	18E4XXXX	100	Cyclic	1	8,40	0
X66	18E4XXXX	100	Cyclic	1	8,70	0
X41	18E5XXXX	100	Cyclic	1	9,00	0
X104	18EBXXXX	50	NoMsgSendType	1	9,30	0
X92	18EB XXXX	50	NoMsgSendType	1	9,60	0
X30	18EB XXXX	50	NoMsgSendType	1	9,90	0
X4	18EC XXXX	1000	IfActive	1	10,20	0
X118	18EC XXXX	1000	IfActive	1	11,20	0
X20	18EC XXXX	1000	IfActive	1	11,50	0
X15	18F0XXXX	100	Cyclic	1	11,80	0
X23	18F0 XXXX	100	Cyclic	1	12,10	0
X21	18F0XXXX	100	Cyclic	1	12,40	0
X68	18F0XXXX	100	Cyclic	1	12,70	0
X75	18F0XXXX	500	Cyclic	1	13,00	0
X105	18F0XXXX	20	Cyclic	1	13,30	0
X91	18FDXXXX	1000	Cyclic	1	13,60	0
X6	18FDXXXX	100	Cyclic	1	14,00	0
X24	18FEXXXX	100	Cyclic	1	14,30	0
X87	18FEXXXX	100	Cyclic	1	14,60	0
X16	18FE XXXX	100	Cyclic	1	14,90	0
X83	18FE XXXX	100	Cyclic	1	15,20	0
X93	18FE XXXX	1000	Cyclic	1	15,50	0
X94	18FE XXXX	1000	Cyclic	1	15,80	0
X8	18FE XXXX	100	Cyclic	1	16,10	0
X57	18FE XXXX	100	Cyclic	1	16,40	0
X35	18FEXXXX	1000	Cyclic	1	16,70	0
X88	18FE XXXX	1000	Cyclic	1	17,10	0
X61	18FE XXXX	1000	Cyclic	1	17,40	0
X9	18FE XXXX	1000	Cyclic	1	17,70	0
X42	18FEXXXX	250	Cyclic	1	18,00	0
X10	18FEXXXX	1000	Cyclic	1	18,30	0
X65	18FE XXXX	1000	Cyclic	1	18,60	0
X36	18FEXXXX	1000	Cyclic	1	18,90	0
X13	18FEXXXX	100	Cyclic	1	19,20	0
X103	18FEXXXX	1000	Cyclic	1	19,50	0
X101	18FEXXXX	500	Cyclic	1	19,80	0
X43	18FEXXXX	100	Cyclic	1	20,10	0
X96	18FE XXXX	100	Cyclic	1	23,60	0
X62	18FE XXXX	100	Cyclic	1	23,90	0
X14	18FE XXXX	1000	Cyclic	1	24,20	0
X79	18FEXXXX	500	Cyclic	1	24,50	0
X17	18FEXXXX	1000	Cyclic	1	24,80	0
X39	18FEXXXX	1000	Cyclic	1	25,10	0
X58	18FFXXXX	100	Cyclic	1	25,40	0
X25	18FFXXXX	1000	Cyclic	1	25,70	0
X45	18FFXXXX	5000	Cyclic	1	26,00	0
X100	18FFXXXX	5000	Cyclic	1	26,30	0
X51	18FFXXXX	5000	Cyclic	1	26,70	0
X102	18FFXXXX	5000	Cyclic	1	27,00	0
X26	18FFXXXX	100	Cyclic	1	27,30	0
X67	18FFXXXX	5000	Cyclic	1	27,60	0
X59	18FFXXXX	1000	Cyclic	1	27,90	0
X28	18FFXXXX	1000	Cyclic	1	28,20	0
X97	18FFXXXX	250	Cyclic	1	28,50	0
X46	18FFXXXX	50	Cyclic	1	28,80	0
X55	18FFXXXX	100	Cyclic	1	29,10	0
X29	18FFXXXX	1000	Cyclic	1	29,40	0
X32	18FFXXXX	1000	Cyclic	1	29,80	0
X48	18FFXXXX	1000	Cyclic	1	30,10	0
X64	1CFEXXXX	5000	Cyclic	1	31,00	0

TIMING ANALYSIS OF SCANIA T VEHICLE YELLOW BUS

Message Name	Message ID	Cycle ms	Type	Total Message inv. During BP	Response Time R1 ms	Response Time R2 ms
X40	FFXXXX	1000	Cyclic	1	1,20	0
X90	CD1XXXX	100	IfActive	1	1,90	0
X99	CD2XXXX	100	Cyclic	1	2,50	0
X18	CF0XXXX	10	Cyclic	1	3,10	0
X22	CF0XXXX	50	Cyclic	1	3,70	0
X31	CF0XXXX	20	Cyclic	1	4,30	0
X11	CFEXXXX	100	Cyclic	1	5,00	0
X52	CFEXXXX	100	Cyclic	1	5,60	0
X72	CFEXXXX	100	Cyclic	1	6,20	0
X44	CFEXXXX	20	Cyclic	1	6,80	0
X98	CFFXXXX	50	Cyclic	1	7,40	0
X33	CFFXXXX	100	Cyclic	1	8,10	0
X53	CFFXXXX	100	Cyclic	1	8,70	0
X84	CFFXXXX	100	Cyclic	1	9,30	0
X5	CFFXXXX	1000	Cyclic	1	9,90	0
X1	CFFXXXX	200	Cyclic	1	10,50	0
X47	CFFXXXX	1000	Cyclic	1	11,80	0
X80	CFFXXXX	1000	Cyclic	1	12,40	0
X37	CFFXXXX	1000	Cyclic	1	13,00	0
X76	CFFXXXX	1000	Cyclic	1	13,60	0
X54	CFFXXXX	1000	Cyclic	1	14,30	0
X86	CFFXXXX	100	Cyclic	1	14,90	0
X63	CFFXXXX	100	Cyclic	1	15,50	0
X77	CFFXXXX	100	Cyclic	1	16,10	0
X85	CFFXXXX	100	Cyclic	1	16,70	0
X82	10FFXXXX	100	Cyclic	1	17,40	0
X69	10FFXXXX	100	Cyclic	1	18,00	0
X71	18D0XXXX	100	Cyclic	1	18,60	0
X41	18E5XXXX	100	Cyclic	1	19,20	0
X104	18EBXXXX	50	NoMsgSendType	1	19,80	0
X4	18ECXXXX	1000	IfActive	1	20,50	0
X15	18F0XXXX	100	Cyclic	1	22,90	0
X21	18F0XXXX	100	Cyclic	1	23,60	0
X68	18F0XXXX	100	Cyclic	1	24,20	0
X75	18F0XXXX	500	Cyclic	1	24,80	0
X91	18FDXXXX	1000	Cyclic	1	25,40	0
X6	18FDXXXX	100	Cyclic	1	26,00	0
X24	18FEXXXX	100	Cyclic	1	26,70	0
X87	18FEXXXX	100	Cyclic	1	27,30	0
X73	18FEXXXX	100	Cyclic	1	27,90	0
X106	18FEXXXX	100	Cyclic	1	28,50	0
X16	18FEXXXX	100	Cyclic	1	29,10	0
X83	18FEXXXX	100	Cyclic	1	29,80	0
X93	18FEXXXX	1000	Cyclic	1	30,40	0
X109	18FEXXXX	100	Cyclic	1	31,60	0
X94	18FEXXXX	1000	Cyclic	1	32,20	0
X8	18FEXXXX	100	Cyclic	1	32,90	0
X57	18FEXXXX	100	Cyclic	1	33,50	0
X35	18FEXXXX	1000	Cyclic	1	34,10	0
X88	18FEXXXX	1000	Cyclic	1	34,70	0
X61	18FEXXXX	1000	Cyclic	1	35,30	0
X9	18FEXXXX	1000	Cyclic	1	36,00	0
X112	18FEXXXX	1000	Cyclic	1	36,60	0
X107	18FEXXXX	1000	Cyclic	1	37,20	0
X111	18FEXXXX	1000	Cyclic	1	37,80	0
X81	18FEXXXX	1000	Cyclic	1	38,40	0
X10	18FEXXXX	1000	Cyclic	1	39,10	0
X65	18FEXXXX	1000	Cyclic	1	39,70	0
X108	18FEXXXX	1000	Cyclic	1	40,30	0
X36	18FEXXXX	1000	Cyclic	1	42,80	0
X110	18FEXXXX	100	Cyclic	1	43,40	0
X13	18FEXXXX	100	Cyclic	1	44,00	0
X103	18FEXXXX	1000	Cyclic	1	44,60	0
X115	18FEXXXX	500	Cyclic	1	45,30	0
X43	18FEXXXX	100	Cyclic	1	45,90	0
X119	18FEXXXX	100	Cyclic	1	46,50	0
X62	18FEXXXX	100	Cyclic	1	47,10	0
X117	18FEXXXX	1000	Cyclic	1	47,70	0
X14	18FEXXXX	1000	Cyclic	1	48,40	0
X79	18FEXXXX	500	Cyclic	1	49,00	0
X39	18FEXXXX	1000	Cyclic	1	49,60	0
X58	18FFXXXX	100	Cyclic	1	50,20	0
X115	18FFXXXX	100	Cyclic	1	53,30	0
X45	18FFXXXX	5000	Cyclic	1	53,90	0
X118	18FFXXXX	5000	Cyclic	1	54,60	0
X114	18FFXXXX	5000	Cyclic	1	55,20	0
X116	18FFXXXX	5000	Cyclic	1	55,80	0
X59	18FFXXXX	1000	Cyclic	1	56,40	0
X28	18FFXXXX	1000	Cyclic	1	57,00	0
X97	18FFXXXX	250	Cyclic	1	57,70	0
X117	18FFXXXX	250	Cyclic	1	58,30	0
X95	18FFXXXX	100	Cyclic	1	58,90	0
X119	18FFXXXX	100	Cyclic	1	59,50	0
X50	18FFXXXX	100	Cyclic	1	60,10	0
X2	18FFXXXX	100	Cyclic	1	62,60	0
X46	18FFXXXX	50	Cyclic	2	63,20	13,90
X55	18FFXXXX	100	Cyclic	1	64,50	0
X29	18FFXXXX	1000	Cyclic	1	65,10	0
X122	18FFXXXX	1000	Cyclic	1	65,70	0

X32	18FFXXXX	1000	Cyclic	1	66,30	0
X123	18FFXXXX	1000	Cyclic	1	67,00	0
X129	18FFXXXX	1000	Cyclic	1	67,60	0
X124	18FFXXXX	1000	Cyclic	1	68,20	0
X48	18FFXXXX	1000	Cyclic	1	68,80	0
X128	18FFXXXX	1000	Cyclic	1	69,40	0
X125	1CDEXXXX	1000	Cyclic	1	70,10	0
X64	1CFEXXXX	5000	Cyclic	1	71,30	0
X7	1CFFXXXX	1000	Cyclic	1	71,90	0
X127	1CFFXXXX	1000	Cyclic	1	72,50	0
X130	1CFFXXXX	1000	Cyclic	1	73,20	0
X137	1CFFXXXX	1000	Cyclic	1	73,80	0

TIMING ANALYSIS OF SCANIA T VEHICLE GREEN BUS

Message Name	Message ID	Cycle ms	Type	Total Message inv. During BP	Response Time R1 ms	Response Time R2 ms
X22	CF0XXXX	50	Cyclic	1	1,20	0
X31	CF0XXXX	20	Cyclic	1	1,90	0
X44	CFEXXXX	20	Cyclic	1	2,50	0
X98	CFFXXXX	50	Cyclic	1	3,10	0
X84	CFFXXXX	100	Cyclic	1	3,70	0
X1	CFFXXXX	200	Cyclic	1	4,30	0
X71	18D0XXXX	100	Cyclic	1	5,00	0
X133	18E0XXXX	1000	Cyclic	1	5,60	0
X136	18E0XXXX	1000	Cyclic	1	6,20	0
X15	18F0XXXX	100	Cyclic	1	6,80	0
X23	18F0XXXX	100	Cyclic	1	7,40	0
X21	18F0XXXX	100	Cyclic	1	8,10	0
X68	18F0XXXX	100	Cyclic	1	8,70	0
X105	18F0XXXX	20	Cyclic	1	9,30	0
X6	18FDXXXX	100	Cyclic	1	9,90	0
X132	18FDXXXX	1000	Cyclic	1	10,50	0
X93	18FEXXXX	1000	Cyclic	1	11,20	0
X94	18FEXXXX	1000	Cyclic	1	11,80	0
X57	18FEXXXX	100	Cyclic	1	12,40	0
X42	18FEXXXX	250	Cyclic	1	13,00	0
X36	18FEXXXX	1000	Cyclic	1	13,60	0
X110	18FEXXXX	100	Cyclic	1	14,30	0
X103	18FEXXXX	1000	Cyclic	1	14,90	0
X115	18FEXXXX	500	Cyclic	1	15,50	0
X43	18FEXXXX	100	Cyclic	1	16,10	0
X62	18FEXXXX	100	Cyclic	1	16,70	0
X135	18FEXXXX	1000	Cyclic	1	17,40	0
X14	18FEXXXX	1000	Cyclic	1	18,00	0
X79	18FEXXXX	500	Cyclic	1	18,60	0
X39	18FEXXXX	1000	Cyclic	1	19,20	0
X131	18FFXXXX	1000	Cyclic	1	19,80	0
X134	18FFXXXX	1000	Cyclic	1	20,50	0
X28	18FFXXXX	1000	Cyclic	1	22,90	0
X97	18FFXXXX	250	Cyclic	1	23,60	0
X122	18FFXXXX	1000	Cyclic	1	24,20	0
X32	18FFXXXX	1000	Cyclic	1	24,80	0
X123	18FFXXXX	1000	Cyclic	1	25,40	0
X129	18FFXXXX	1000	Cyclic	1	26,00	0