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# Worldwide Harmonized Heavy Duty Emissions Certification Procedure

## Final Summary

### 15th WHDC, Geneva, 21 May 2003

# Content

- Basic test cycle development
  - Vehicle cycle (WVTC)
  - Drivetrain model
  - Engine test cycles WHTC and WHSC
- Development of ISO procedures
  - Emissions measurement
  - Engine family
- Test cycle validation step 1
- Development of WHTC version 2
- Development of more robust test cycle denormalization procedure
- Final test cycles WHTC and WHSC
- Further work
  - Test cycle validation step 2
  - Draft GTR
  - Round robin test

# History of Events

- Basic test cycle development by RWTÜV and TNO between October 1998 and January 2001 in cooperation with JARI
  - Final report released in June 2001
  - Two test cycles proposed: WHTC (transient), WHSC (steady state)
- Test cycle validation step 1 by EMPA between March 2001 and January 2002
  - Final report released in June 2002
  - Modification of WHTC test cycle necessary to better reflect in-use operation
- Development of WHTC version 2 by RWTÜV by May 2002
  - Report released in June 2002
- Development of more robust test cycle denormalization procedure and WHSC version 2 by RWTÜV by March 2003
  - Report released in March 2003
- Development of ISO procedures
  - Emissions measurement: 1998 to 2001; ISO 16183 published December 2002
  - Engine family: 1998 to 1999; ISO 16185 published October 2000
- Test cycle validation step 2 partly finalized

# Test Cycle Development Approach

A three-step approach was chosen to achieve maximum representativity:

Step 1: Creation of various vehicle reference cycles, including all real-life influences in a representative way ⇒ Far too long for laboratory testing.

Tool: "Classification matrix" for identification of most important influences on engine operation of HD vehicles

Step 2: Compression of reference cycles to laboratory size vehicle test cycle of approx. 30 minutes using approved statistical methods

Step 3: Transformation of v(t), $P_{norm}$(t) pattern of vehicle cycle into $n_{norm}$(t), $M_{norm}$(t) pattern of engine cycle

Tool: Drivetrain model and transformation algorithm

# Basic Test Cycle Development

- Conducted by RWTÜV and TNO between October 1998 and January 2001 in cooperation with JARI
- Based on data from 65 engines
- Novel statistical approach for development of a representative transient vehicle cycle (WTVC)
- Conversion of vehicle cycle WTVC into normalized reference engine cycles
  - Introduction of fixed representative drivetrain model covering 4.6 to 40 ton vehicles
  - Development of transformation algorithm with WTVC, specific engine data and drivetrain model as input
  - Development of Worldwide Harmonized Reference Transient Cycle (WHTC)
  - Development of Worldwide Harmonized Reference Steady State Cycle (WHSC) with weighting factors and speed/load distribution based on WHTC
  - Development of denormalization formula to convert the normalized reference engine test cycles WHTC and WHSC into actual engine test cycles
- Final report released in June 2002

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# Worldwide Transient Vehicle Cycle

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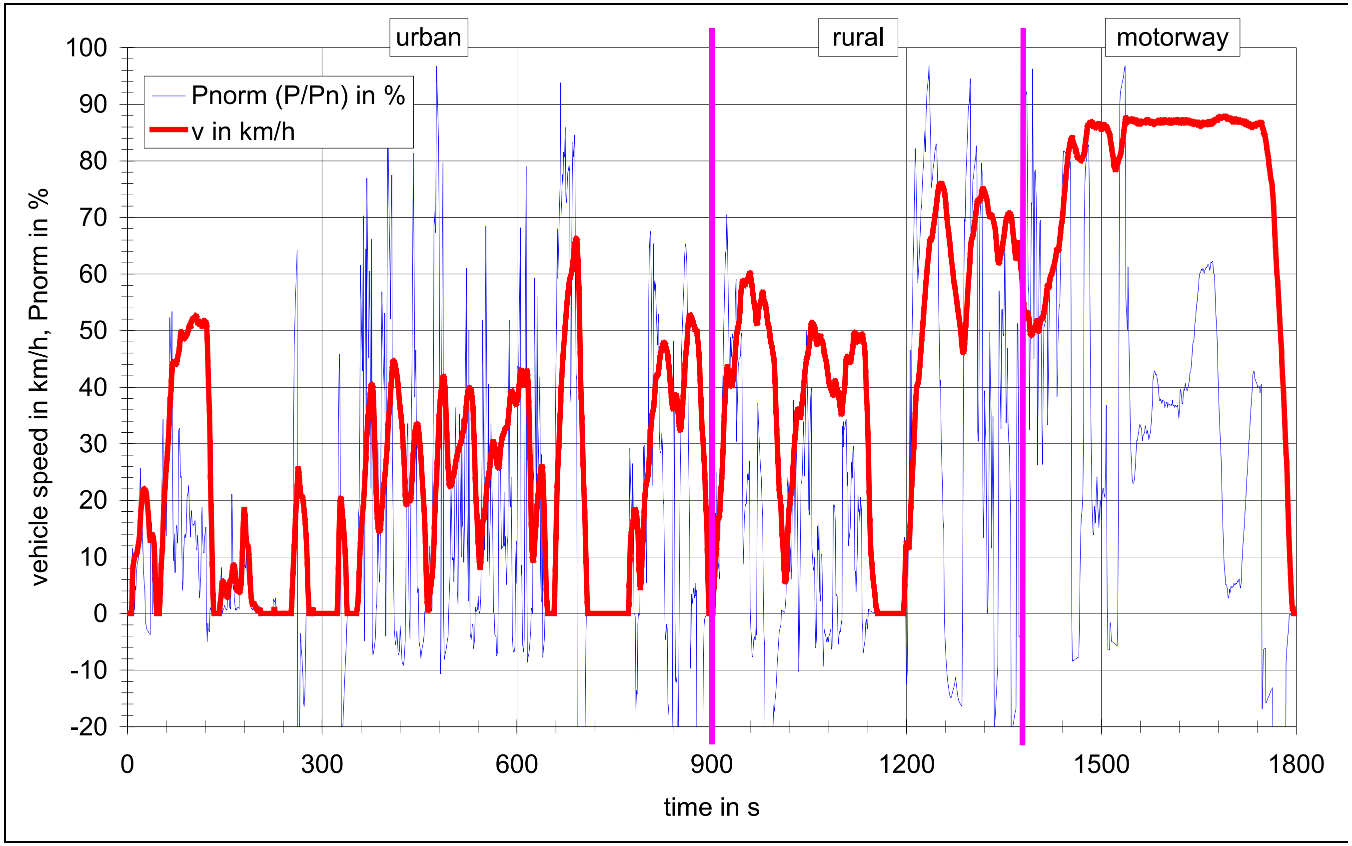
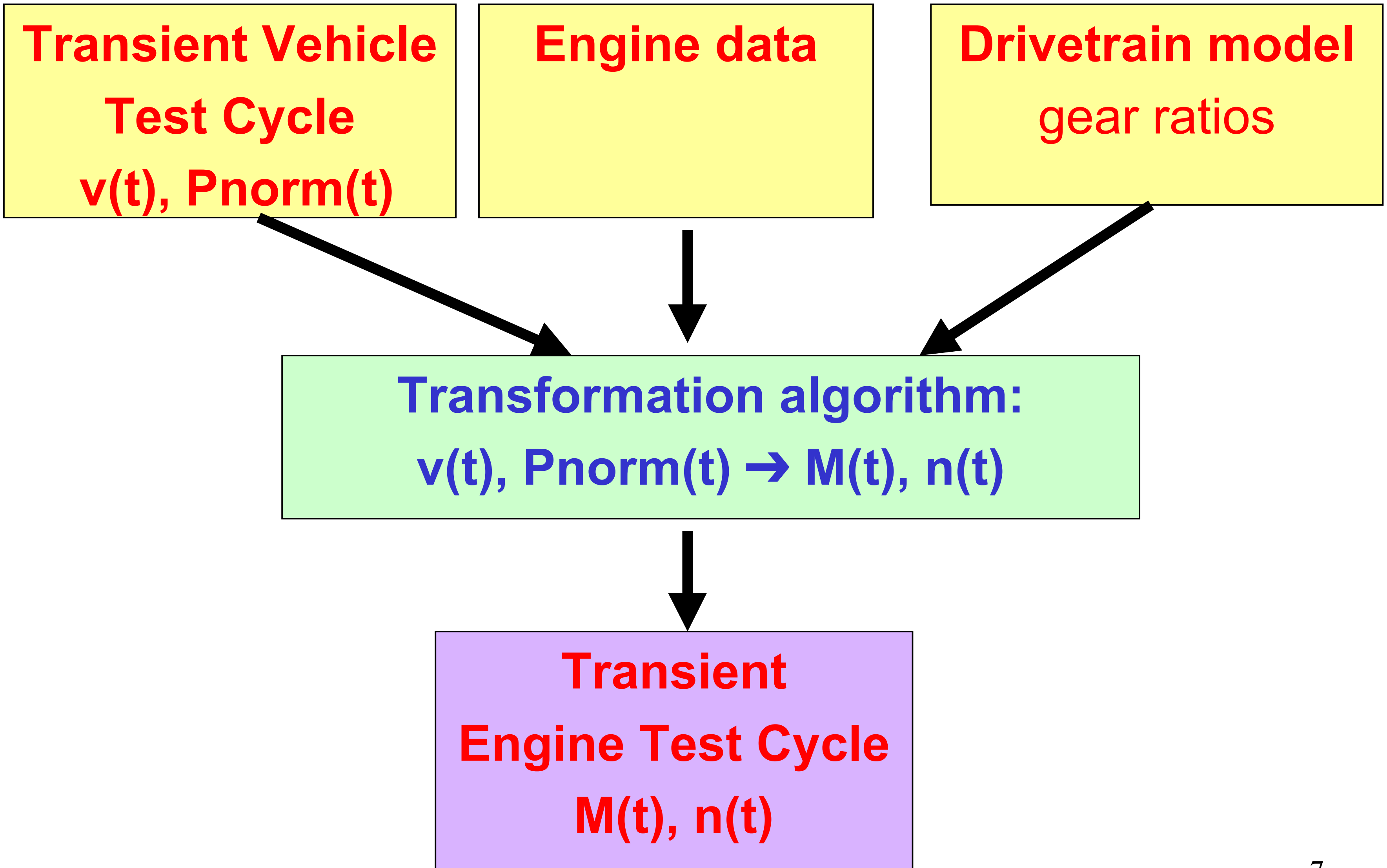



- Basic vehicle test cycle derived from worldwide driving patterns
- Basis for development of reference engine test cycles WHTC and WHSC
- Never changed during further work

# Vehicle to Engine Cycle Conversion



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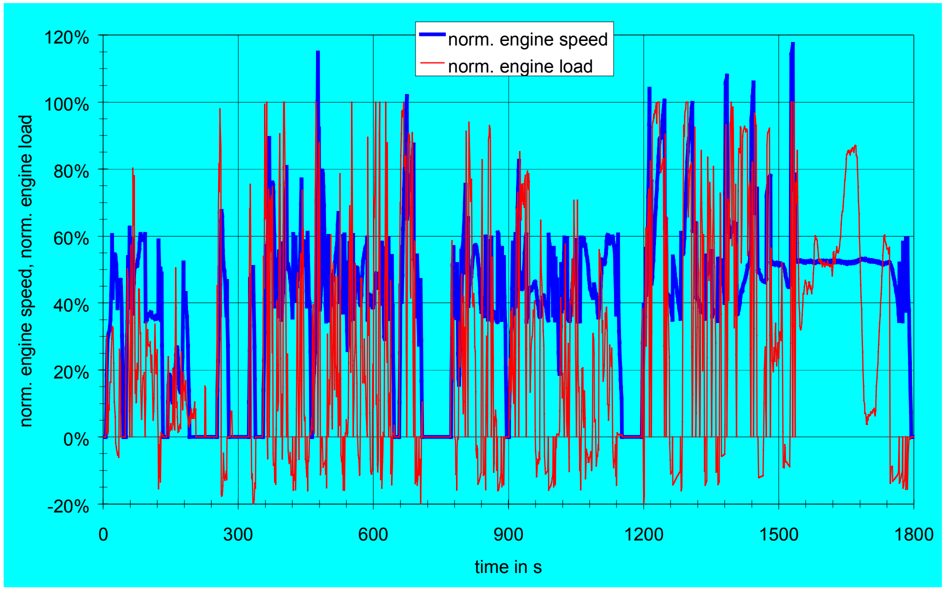
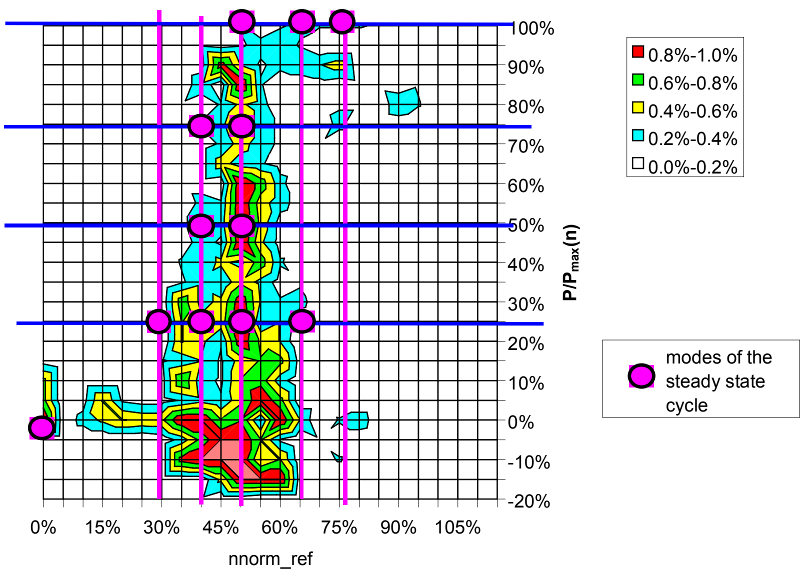
# The WHDC Reference Engine Cycles Original Version 1






WHTC




WHSC

# Development of ISO Procedures Emissions Measurement



- Conducted by ISO TC 22/SC 5 between October 1998 and December 2001
- Emissions measurement procedure (ISO 16183)
  - Partial flow dilution (PFS) PM measurement system for transient cycles
  - Raw gaseous emissions measurement procedure for transient cycles
- Correlation studies on current test cycles (ESC, ETC, FTP, JAP)
  - Satisfactory correlation between PFS and full flow system (CVS) PM measurement established at four different research institutes
  - Satisfactory correlation between raw and full flow system (CVS) gaseous emissions measurement established at two different research institutes
  - Results from correlation studies used as basis for development of ISO standard 16183
- ISO 16183 published on 09 December 2002

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# Evaluation of Partial Flow Dilution (PFS) vs. Full Flow Dilution Systems

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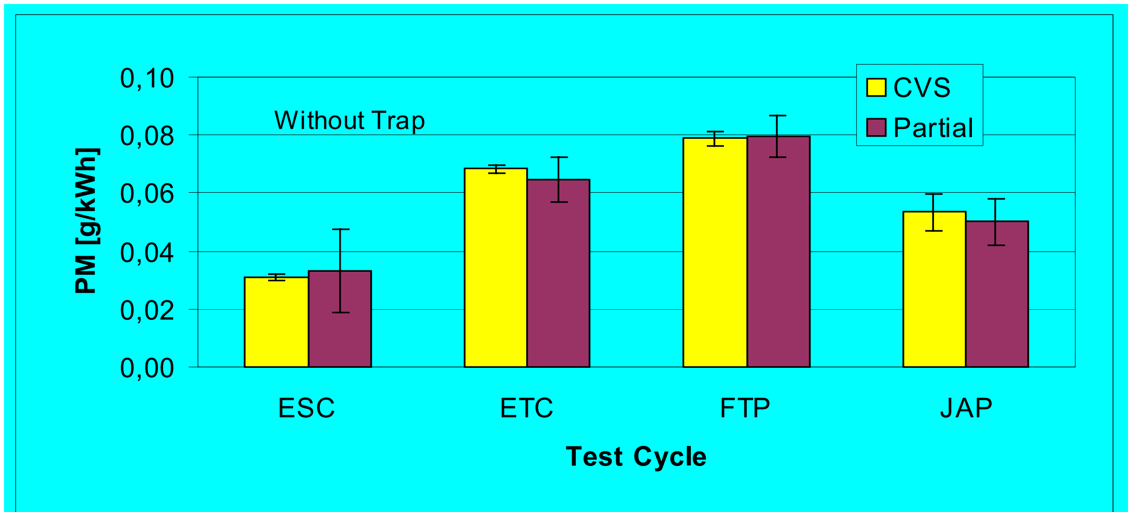


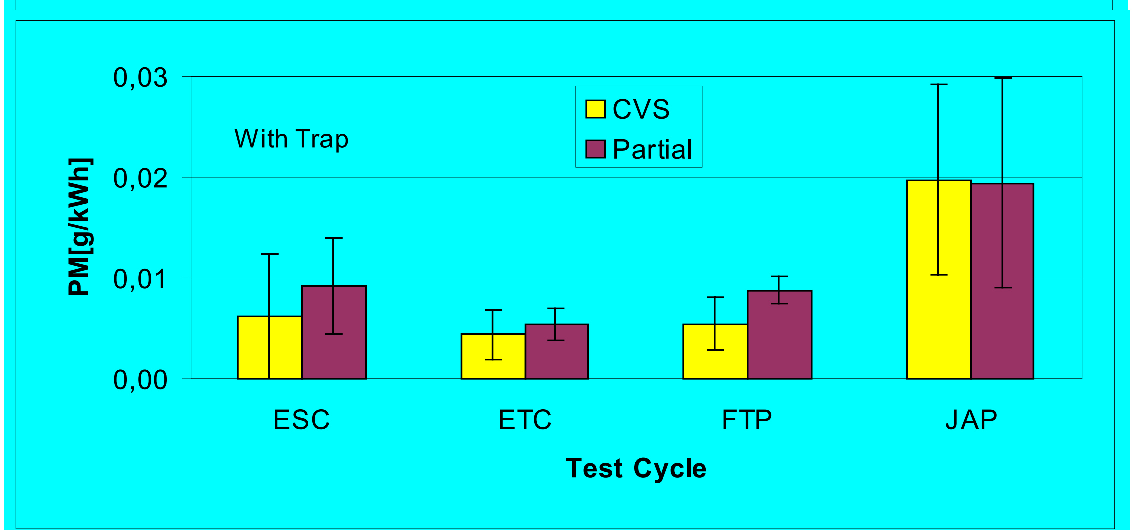


## Results

- Fast response PFS can be applied to transient test cycles
- PM correlation PFS/CVS within ± 15 %
- Test repeatability of 10% possible down to PM levels of 0.01 g/kWh

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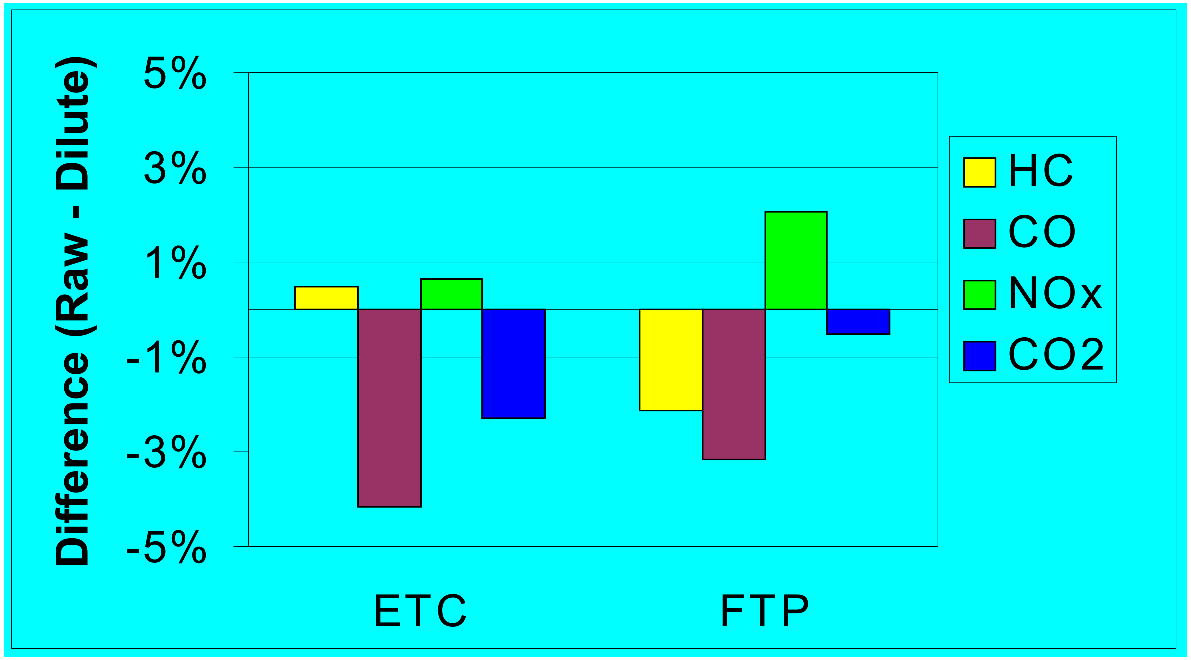
## Conclusion

- PFS suitable for both WHTC and WHSC cycles

# Evaluation of Raw vs. Dilute Gaseous Emissions Measurement






## Results

- Raw measurement can be applied to transient test cycles in conjunction with fast response exhaust flow measurement
- Correlation raw/dilute within ± 5 %

## Conclusion

- Raw measurement suitable for both WHTC and WHSC cycles

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# Development of ISO Procedures Engine Family

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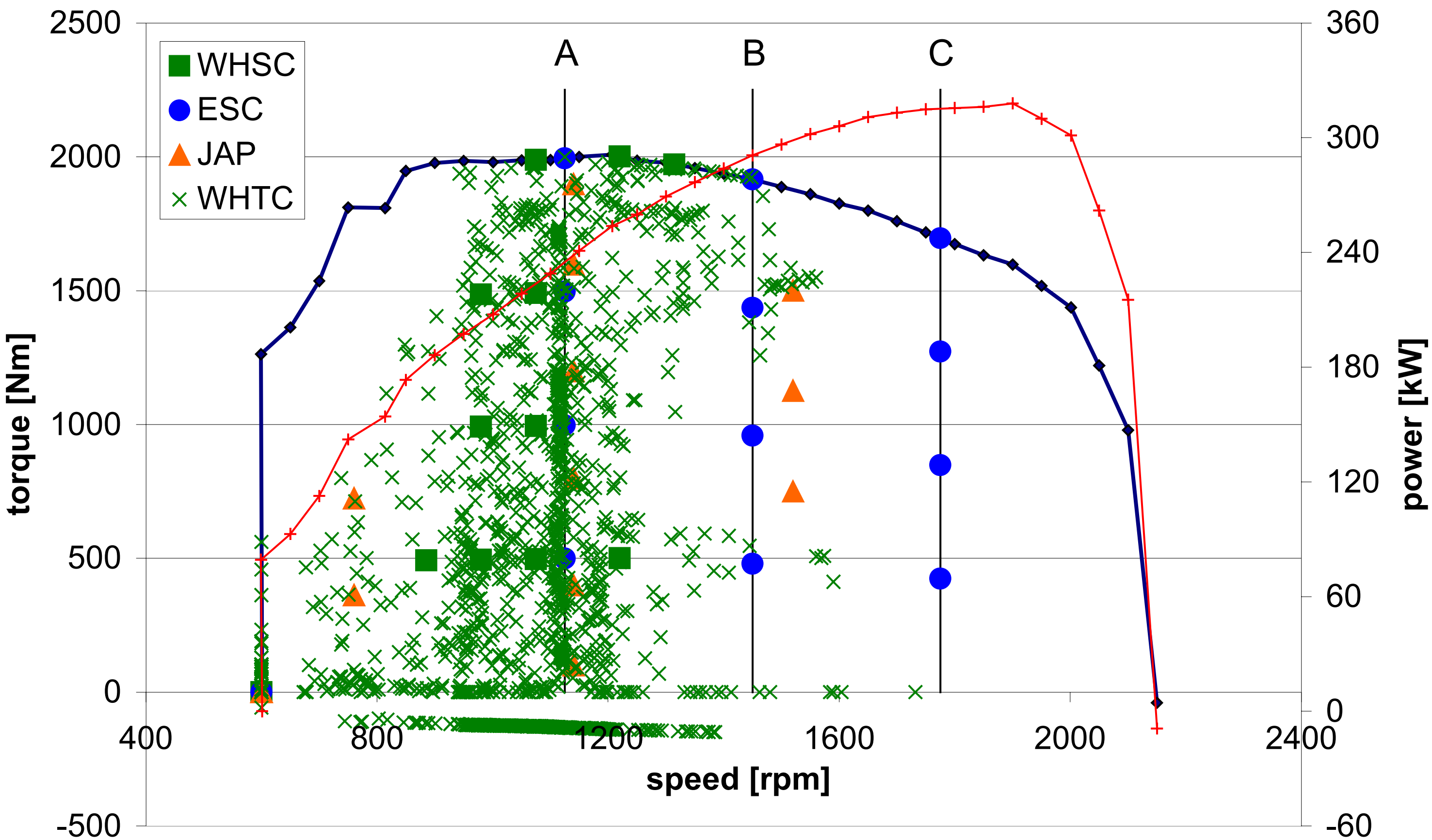
- Conducted by ISO TC 22/SC 5 between October 1998 and December 1999
- Development of ISO standard 16185 was based on existing regulations
  - ISO standard 8178-7 (nonroad engines)
  - US regulation CFR 40 part 86
  - EU Directive 1999/96/EC
- Improvement of existing engine family concepts with respect to SI engines, alternate fuels, aftertreatment system and electronically controlled engines
- Engine family
  - a grouping of engines with similar exhaust emission characteristics
- Parent engine
  - the representative of the family with comparatively high exhaust emission characteristics
- Member of the family
  - any engine of the family except for the parent engine
- Aftertreatment system
  - device for reduction of exhaust emissions externally fitted to the engine, like catalysts, but not integral engine parts, like EGR
- ISO 16185 published on 15 October 2000

# Test Cycle Validation Step 1

- Conducted at EMPA between March 2001 and January 2002
- Results:
  - In terms of cycle work, the WHDC test cycles represent typical in-use operation of commercial vehicles
  - Due to the denormalization formula, the engine speed range on the WHDC test cycles is relatively narrow and mostly towards the low side of the range
  - The driveability of the WHTC on the test bench is good; compared to the current cycles, an improvement is obvious
  - The operation of the WHSC on the test bench is an improvement over the ESC, especially in terms of particulate sampling time
  - The agreement between full and partial flow dilution system was good in this program, especially, if the reproducibility of different full flow systems in a round robin test is taken into account
  - The raw gas measurement generally showed a good agreement to the diluted measurement; for CO, the correlation was acceptable with respect to the CO emission standard

# Test Cycle Validation Step 1
# Speed/load pattern of engine 3






High portion of low speed operation observed, which is not representative of real world driving

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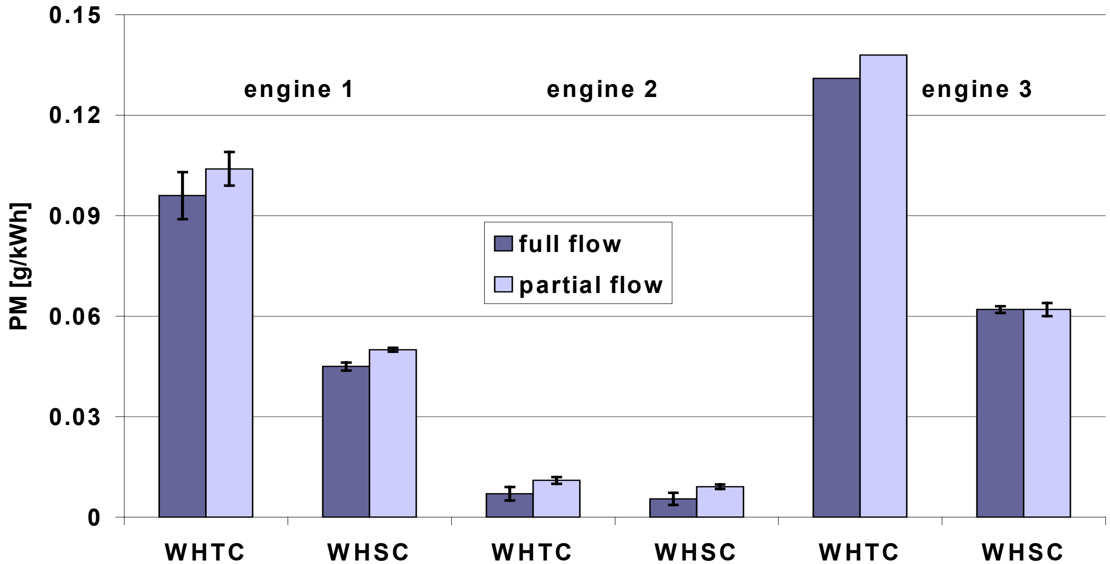
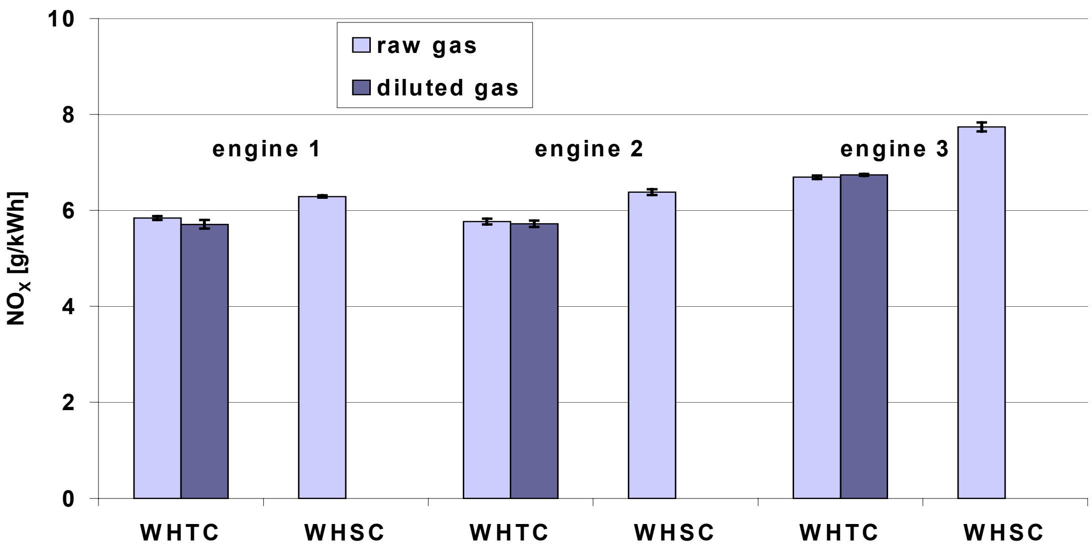
# Test Cycle Validation Step 1
# Correlation to CVS Full Flow






## PM

- Good correlation from ISO studies confirmed for WHTC and WHSC

## NOx

- Good correlation from ISO studies confirmed for WHTC and WHSC

# Development of WHTC Version 2

- Background:
  - Based on WHDC validation step 1, engine speed range is too low
  - Reason is definition of preferred speed n_pref within denormalization formula
  - This leads to too low engine speeds in cases, where the torque is maximum for a wide engine speed range and n_pref as the lower limit of this range is close to n_low
  - In these cases, both reference speeds are close to idling speed and the denormalization results in extreme low test speeds of the WHTC compared to real world operation
- Solution:
  - New definition of preferred speed with n_pref being the centre of the speed range between the minimum speed, where the engine torque is 90% of maximum torque, and the maximum speed, where the engine torque is 90% of maximum torque
  - Since the approximation of the drivetrain model was based on the previous definition for n_pref, the normalized speeds of the WHTC were recalculated
  - The engine database for this recalculation was increased, substantially
- The result is a slightly modified reference cycle and a new denormalization formula

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# Comparison of Old vs. New WHTC for One Specific Engine

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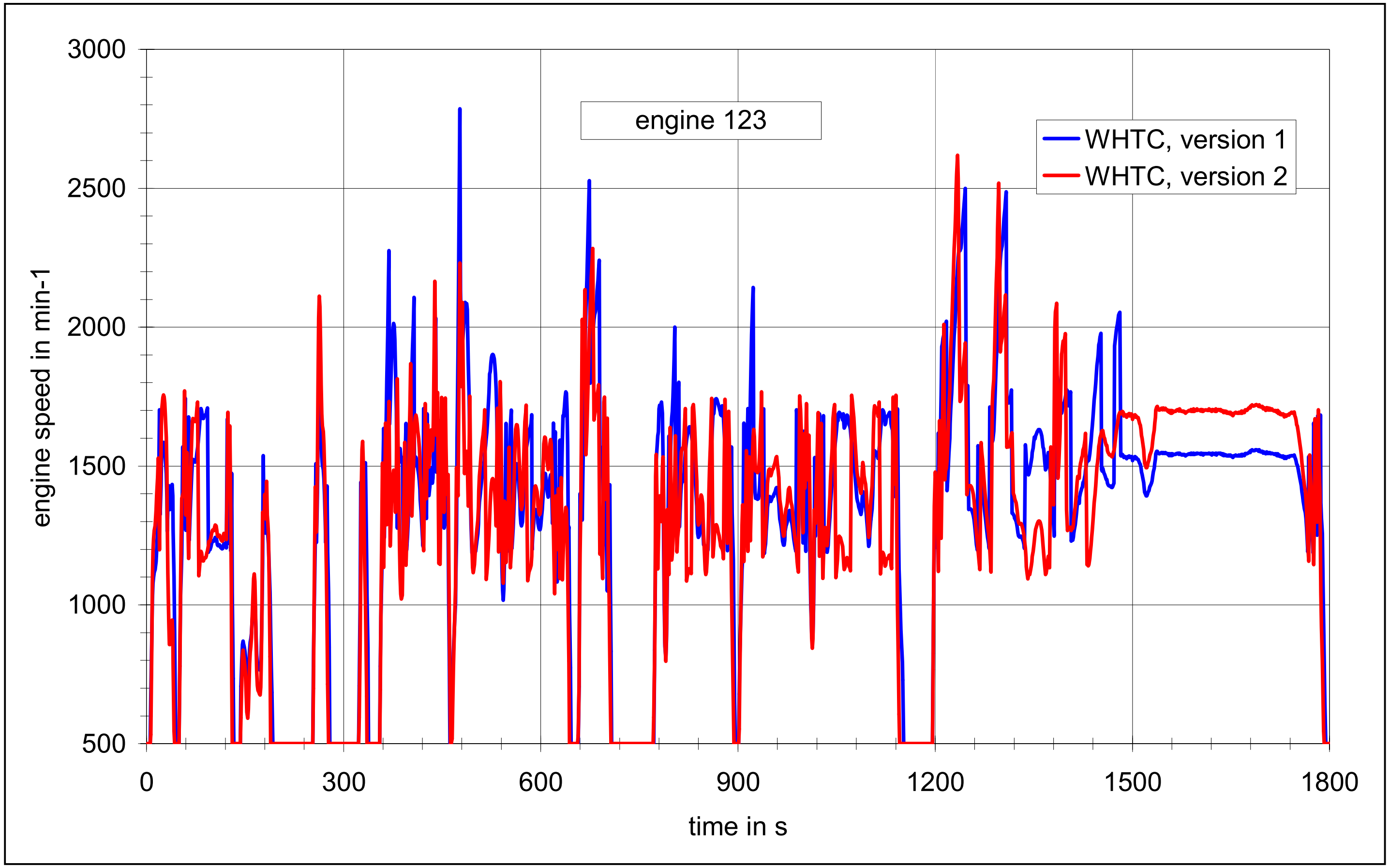


- WHTC version 2 has higher engine speed range as required from validation step 1
- Version 2 is more representative for real world operation

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# Development of More Robust Denormalization Procedure



- Background:
  - New denormalization procedure not robust enough against variations in torque curve design
  - Reason is the potential of electronically controlled engines to influence torque curve design so as to produce a wide range of n_pref and consequently of actual engine test cycles
  - This can lead to torque curve design tampering in order to influence the test speeds in a way to operate the engine on the test cycle outside the typical real world operation
- Solution:
  - New definition of preferred speed with n_pref being the engine speed where the integral of the torque curve from idling speed is 51% of the whole integral from idling speed to n95h and n95h is the highest engine speed where the power output is 95% of rated power
  - This definition is more robust against possible torque curve design tampering of future engines
  - The new definition is an important contribution to the cycle bypass provisions requested from the WHDC group
- The WHTC reference cycle version 2 remains unchanged

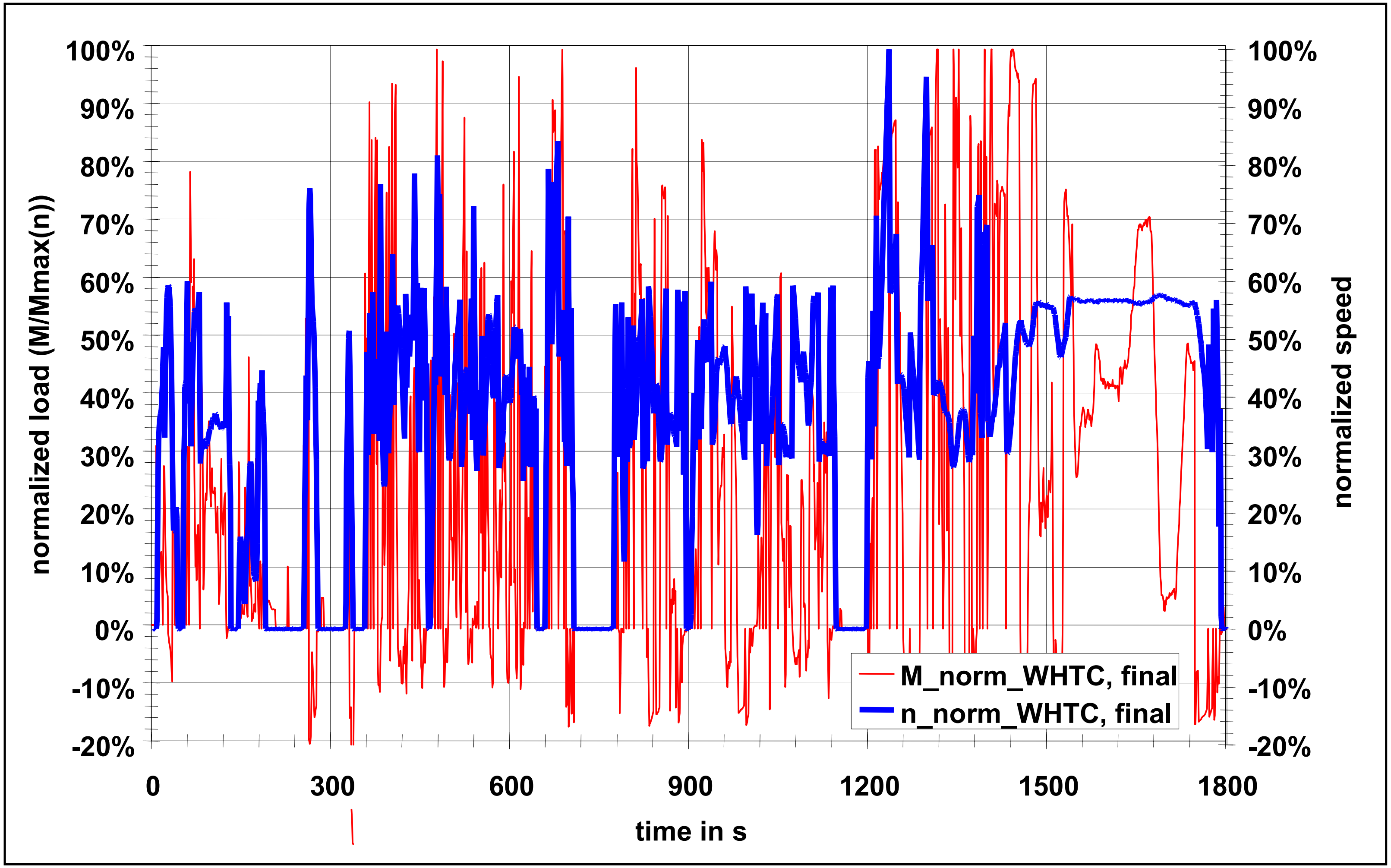
# Consequences for the WHSC



- Since the WHTC version 2 is based on a new reference engine and since this resulted in slight differences in engine speed and torque pattern, the corresponding steady state cycle WHSC needed also to be amended.
- This amendment was based on the same approach as used for the WHSC version 1. The normalized engine speed/load points were based on the joint frequency distribution of the WHTC. An appropriate weighting factor was established for the motoring section in accordance with the WHTC but with zero emissions/power.
- The finally chosen measurement points form a compromise between representativity and the demands of steady state measurement, especially with respect to particulates.

# Final WHTC Reference Cycle Version 2





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# Final WHSC Reference Cycle Version 2

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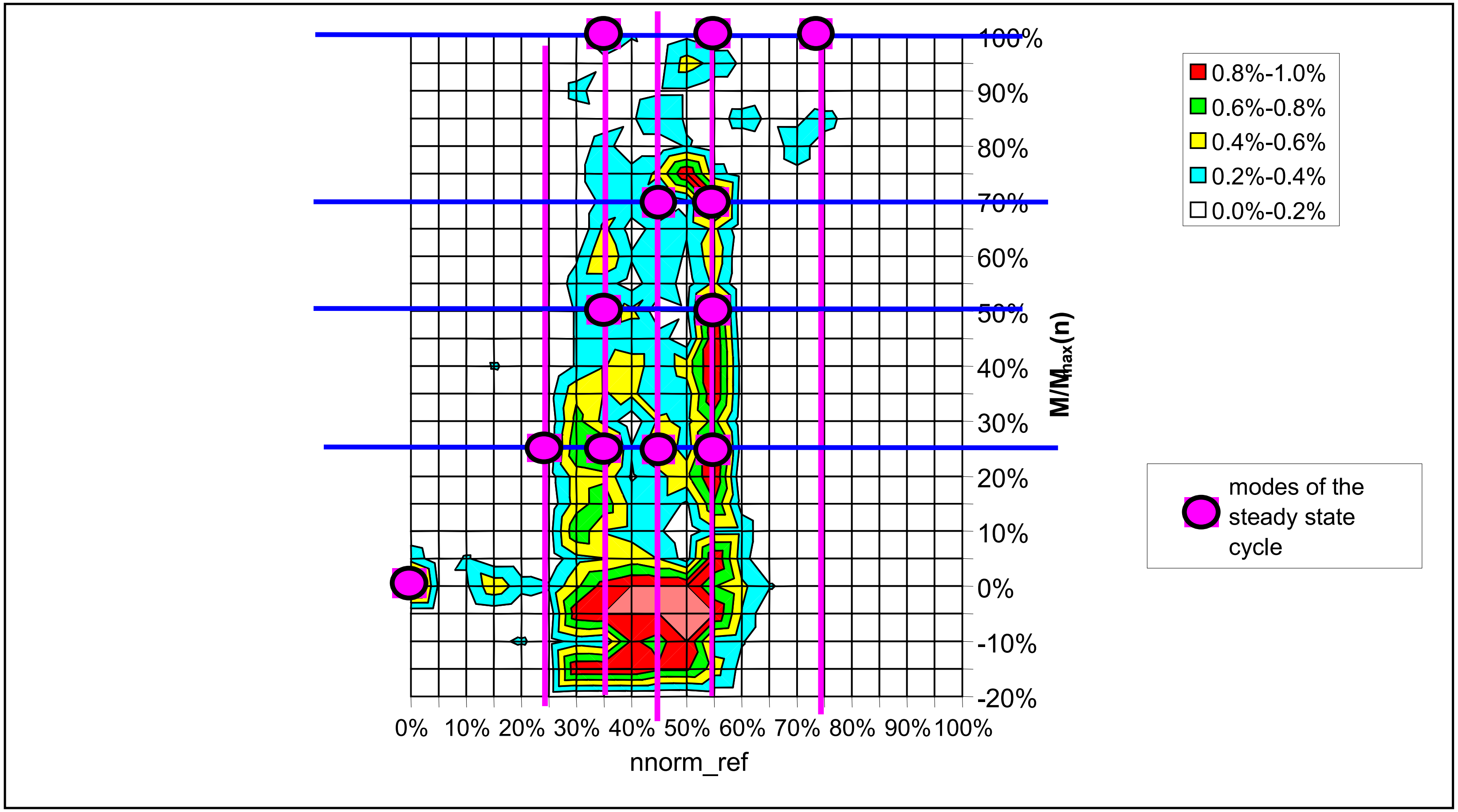

# Summary and Conclusions

- General applicability of WHTC and WHSC cycles demonstrated during validation step 1
- Development of test cycles WHTC and WHSC finalized with modified version 2
- Upgraded denormalization procedure introduced
- Use of partial flow dilution systems and raw gaseous emissions measurement for transient cycles proven and described in ISO 16183
- First draft GTR on WHDC test cycle (technical annexes) to be submitted at May 2003 GRPE session
- Additional validation studies under evaluation or starting soon including gas engines, but no further modification of test procedure expected
- Ongoing WHDC activities
  - evaluation of further emissions validation (step2) by August 2003
  - further development of draft GTR by January 2005
  - Coordination and evaluation of round robin test program (10/2003 to 06/2005)