Swedish Pavement Performance Specification

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Abstract
The need for relatively simple test procedure based on mechanical properties of asphalt concrete has been apparent for many years. It is valuable to be able to use the mechanical/ functional properties in quality control and to relate asphalt layer properties to structural performance of bituminous layers. It is also essential that the test procedure takes in consideration the effect of production, laying and compaction of asphalt mixtures. The procedure must both be suitable for routine use and sufficiently reliable to be used in the specification for asphalt mixes. The use of mechanical properties in the specification of mixes will help in establishing relationship between mix design and pavement design and in turn to link specifications to performance.
The principle in the Swedish specification [ATB VÄG 2002] concerning performance or function is to define requirements in respect to asphalt layer or surface characteristics. The choice of the level depends on the agreement between client and contractor. An overview of the performance specification and evaluation of function-based contracts are presented in this paper.

Definition of performance specification
Performance or functional specification may have different sense depending on the user [PIARC report 2000]. In general, performance or functional specification in Sweden means requirements based on functional properties which describe the function of a product that is important for traffic safety, trafficking, comfort, environment and live cycle costs.

Principles in the Swedish road specifications
The performance or functional specifications principle is to define requirements in respect to asphalt layer or surface characteristics. The Swedish performance specification can be classified as a combination of performance, performance based and end-result specification according to the definition of PIARC Report [2000]. The limits of the functional or performance parameters are usually in correlation with the design traffic which described below:

Traffic design
Traffic volume is needed for the prediction of the deterioration degree caused by repeated loading of bituminous layer. The requirement limits in the Swedish specifications are set in respect to average annual daily traffic (AADT) for each lane. However, different traffic types cause various distresses, e.g. wear rutting is caused primary by passenger cars with studded tyres and flow rutting by heavy vehicles. The design traffic for various distresses are calculated as follows:

For wear rutting; $AADT_{l,adjust} = AADT_l \cdot J_{DD} \cdot J_{SH} \cdot J_{KF} \cdot J_{VH}$

Where $AADT_{l,adjust}$, $AADT_l$, J_{DD}, J_{SH}, J_{KF}, and J_{VH} are AADT passenger cars for the traffic lane, AADT for the traffic lanes, adjusted factors for studded tyre share, traffic speed, lateral distribution of passenger cars and winter maintenance respectively.

For fatigue cracking; $AADT_{l,heavy} = AADT_l \cdot A$

Where $AADT_{l,heavy}$, $AADT_l$ and A are AADT heavy vehicles for the traffic lane, AADT traffic volume for the traffic lane and percent of heavy vehicle respectively.

For flow rutting; $AADT_{l,stab} = AADT_{l,heavy} \cdot J_t \cdot J_h$

Where $AADT_{l,stab}$, $AADT_{l,heavy}$, J_t and J_h are AADT heavy vehicles for the traffic lane adjusted in respect to flow rutting, AADT heavy vehicles for the traffic lane, adjusted factors for lateral distribution of heavy vehicles and traffic speed respectively.

Structural requirements based on asphalt layer characteristics

The idea in the specification in respect to performance or function is to define requirements for each layer rather than for mixes. For example, a base layer must fulfil some requirements in respect to traffic loading and climate conditions, such as resistance to fatigue cracking. The Swedish specification does not, however, emphasise which types of mixes have to be used in base layers. The problem is that all types of mixes can not be evaluated through mechanical tests and/or by taking specimens from pavement layers as is the case concerning thin bituminous layers. Therefore it is in these cases allowed to manufacture specimens in the laboratory. However, higher requirements are set to the laboratory-manufactured specimens in order to ensure adequate asphalt concrete. To cover the most frequent structural distresses in the field, the specification guidelines for asphalt concrete should include at least test procedures for flow rutting, fatigue cracking, stiffness, wear, and water sensitivity for Swedish conditions. Test procedures are as follows:

Stiffness modulus

Flexibility and load distribution capacity are two important characteristics of bitumen bound layers. High stiffness bituminous layers protect underlying layers by better stress distribution resulting in less stress applied to the underlying pavement layers. Low stiffness bituminous layers are flexible and desired in thin pavement structures with low traffic loading, where the purpose of the asphalt layer is not primary to increase the bearing capacity of the road, but rather to increase riding comfort and safety and to protect underlying layers. Stiffness of bituminous layer is one of the most important parameters in analytical pavement design.
Stiffness modulus is measured on cylindrical cores from asphalt layers using Indirect Tensile Test and according to Swedish standard (FAS method 454). The effect of age has been found very significant especially during the first year after laying. The following regression equation can be used to calculate the stiffness modulus of asphalt concrete layer in respect to age. This relationship is based on a number of cores taken from pavement layers at different occasions over a five-year period.

$$S_{t_2} = S_{t_1} \cdot (t_2 / t_1)^{0.08}$$

where

S_{t2}	is the stiffness modulus at t_2 in MPa
S_{t_1}	is the stiffness modulus at t_1 in MPa
t_1& t_2	are the age of the bituminous layer in months

The stiffness modulus of a one-year-old pavement layer has been taken as the initial stiffness modulus in evaluation of bituminous layers. The structural functional characteristics requirements in respect to stiffness modulus of pavement layers are shown in Table 1. These values are based on earlier measurements on cores from existed pavement layers, which were normally about 1 year old.

Table 1 Stiffness modulus requirements in MPa.

Layer	**Temperature, °C**		
	+5	+10	+20
Surfacing	< 12 000	3 000 - 10 000	> 2 000
Binder course	< 15 000	8 000 - 13 000	> 4 000
Base	< 13 000	4 000 - 10 000	> 2 000

Fatigue cracking

Fatigue failure of a bituminous layer means the development of cracks in the pavement layer caused by repeated traffic loading. Fatigue testing is time consuming and it is known that the fatigue property of asphalt concrete is well correlated with the stiffness of the material. Therefore fatigue testing is only recommended when using new type of mixes (not tested before) or if there are particular reasons. Requirements on fatigue resistance of asphalt layers are based on traffic volume and stiffness modulus of asphalt concrete at 10°C as shown in Table 2. The allowed tensile strain at specified traffic volume is calculated from fatigue criterion of bituminous mixtures that depends on the stiffness modulus of the asphalt concrete layer. The fatigue criterion in the Swedish specification is based on laboratory measurements on cores and calibrated with the field-based criterion. The fatigue relationship can be used in stead of requirements in Table 2.

Table 2 Requirements on tensile strain with respect to fatigue cracking as a function of design traffic.

Layer	**Parameter**	**$AADT_{l,heavy}$ in Thousands**			
		< 0.5	**0.5 - 1.0**	**1.0 - 2.0**	**> 2.0**
Surfacing	Stiffness at 10°C, MPa	< 4000	3000 - 5000	4000 - 6000	6000 - 10000
	Tensile strain, με	100 - 500	100 - 170	80 - 100	60 - 80
Binder course	Stiffness at 10°C, MPa	-	8000 - 10000	10000 - 12000	> 12000
	Tensile strain, με	-	80 - 100	60 - 80	< 60
Base	Stiffness at 10°C, MPa	< 4000	4000 - 6000	6000 - 10000	6000 - 10000
	Tensile strain, με	100 - 190	80 - 100	< 80	< 80

Flow rutting

In spite of the cold climate in Sweden, flow rutting is one of the most frequent types of distress in high volume roads. This is primarily due to the use of softer binders. Resistance of asphalt concrete layer to flow rutting is measured on cylindrical cores of pavement layer using Repeated Axial Creep Test according to Swedish Standard (FAS Method 468). The structural functional characteristic requirements in respect to flow rutting resistance of the asphalt pavement layers are shown in Table 3. However, due to practical difficulties there are no requirements on bituminous layers with a thickness less than 25 mm. Bituminous layers with a thickness 25-40 mm could be tested on specimens compacted in the laboratory after approval from Road Agency. These requirements are based on earlier experiences with creep tests on cores. As is the case with the stiffness modulus, the effect of the age has been found very significant on the creep results. Therefore a similar relationship has been determined for creep tests. The following equation can be used to calculate the creep deformation of asphalt concrete layer in respect to age.

$$D_{t_2} = D_{t_1} \cdot (t_1 / t_2)^{0.23}$$

where

D_{t_2} is the permanent strain at t_2 in $\mu\varepsilon$

D_{t_1} is the permanent strain at t_1 in $\mu\varepsilon$

t_1& t_2 are the age of the bituminous layer in months

Table 3 Requirements on creep deformation as a function of design traffic

$AADT_{l,stab}$	**Permanent strain in $\mu\varepsilon$**		
	Surfacing	**Binder course**	**Base**
Extreme load	< 12500	< 10000	< 12500
> 3600	< 15000	10000 - 12500	12500 - 15000
1800 - 3600	15000 - 20000	12500 - 15000	15000 - 20000
900 - 1800	20000 - 30000	15000 - 20000	20000 - 30000
450 - 900	30000 - 40000	20000 - 30000	30000 - 40000
< 450	-	-	-

Wear rutting

Rutting caused by passenger cars with studded tyres is one of the major cause of pavement deterioration on heavily trafficked roads in Sweden. Therefore the choice of aggregate type and mix design are important parameters to limit this type of rutting. Wearing resistance of asphalt concrete is measured on cylindrical cores from pavement layers using Prall method according to Swedish preliminary Standard (FAS Method 471). Bituminous layers with a thickness less than 25 mm shall be tested on specimens compacted in the laboratory. Table 4 shows the requirements on wearing resistance of bituminous layers as a function of design traffic. These requirements are calculated with a wearing model. For more precise prediction of wear rutting with time the use of the model is recommended in the specifications.

Table 4 Requirements on wearing resistance as a function of design traffic for surfacing layer.

$AADT_{l,adjust}$ in Thousands	**Prall-value in cm^3**
> 7000	< 25
3500 -7000	25 - 32
1500 - 3500	33 - 39
500 - 1500	40 - 50
< 500	-

Water sensitivity

Durability of bituminous layers especially against water and moisture effect is one of the most serious factors contributing to the degradation of asphalt pavements in Sweden. Freeze-thaw conditions have also the potential to lessen the cohesive strength and stiffness of the asphalt layers. Water sensitivity of asphalt concrete is determined by testing cylindrical cores of pavement layers using indirect tensile test. The Indirect Tensile Strength Ratio (ITSR) (adhesion value) is obtained by the ratio of tensile strength of conditioned samples to unconditioned samples according to the Swedish Standard (FAS Method 446). Bituminous layers with a thickness less than 40 mm shall be tested on specimens compacted in the laboratory. The specimens shall be compacted to the air void content expected in the field. The ITSR value shall be larger than 75 percent for bituminous layers.

Functional requirements based on surface characteristics

Requirements based on surface characteristics are mainly correlated with traffic safety and riding comfort. For some properties, such as evenness, more than one test method is accepted in order to be practical. It should be mentioned that much effort has been put into evaluating the variability and in establishing acceptance limits. Usually the requirements on road surface characteristic are related to road type, traffic volume, environmental parameters etc by client. The general requirements for the most frequent surface deterioration are described below:

Friction

The skid resistance of road surface is defined by determination of friction coefficient usually using slip wheel friction test. The friction coefficient values should not be less than 0.5.

Evenness

The roughness of pavement surface is determined from longitudinal profile by calculating IRI (International Roughness Index) values. The maximum allowable IRI values, depending on road category is normally between 0.9 to 1.5 mm/m over 400-m road section.

Case study

Road 610 Brotorpet

This road is located in Halland province in the west of Sweden. The road is about 5 km long and 9 m wide. The AADT is about 8 500 vehicles with about 5 percent heavy traffic and maximum speed 90 km/h. The contractor is responsible for design, building and warranties on performance of the road. The warranty period is 7 years, which is believed to be long enough for defects to become evident and to avoid any premature deterioration. Performance requirements and bonus/penalty values are presented below according to the contractual plan.

1. Performance requirements and bonus/penalty values at opening of the road
(1 SEK ≃ 0.1€), (surfacing = wearing course, base = roadbase)

Table 5 Wearing resistance (studded tires)

Target value	**Bonus**	**Penalty**
	2 SEK/m^2	**2 SEK/m^2**
27 cm^3	< 25 cm^3	30-36 cm^3

Table 6 Water sensitivity

Asphalt layer	**Target value**	**Bonus**		**Penalty**	**Test method**
		2 SEK/m^2	**3 SEK/m^2**	**2 SEK/m^2**	
Base	60 %	≥ 75 %	-	50 – 55 %	FAS Method 449
Binder course	75 %	≥ 79 %	-	60 – 69 %	
Surfacing	75 %	79 – 85 %	> 85 %	63 – 69 %	

Flow stability
Target value for creep deformation is < 25000 microstrain for binder course according to the Swedish standard for creep test (FAS Method 468).

Skid resistance
Friction coefficient must be greater than 0.5 according to test method VVMB 104.

Homogeneity
Density measurements by rolling density gauge, DOR

Crossfall
Target value should be less 0±0.26 %, according to test method VVMB 111.

Table 7 Longitudinal profile, IRI

Target value	Bonus		Penalty		
	5 SEK/m²	10 SEK/m²	5 SEK/m²	10 SEK/m²	20 SEK/m²
1.20 mm/m	0.90-1.10 mm/m	<0.90 mm/m	1.30-1.40 mm/m	1.40-1.50 mm/m	1.50-1.65 mm/m

Bearing capacity
Evaluation of bearing capacity is based on Falling Weight Deflectometer measurements. A simple predictor, called Structural Index (SI), is used to classify the road or sections of the road in respect to pavement performance. The Structural Index (Figure 1) is an expression based only on calculated strain from deflection measurements according to Swedish standard VVMB 114 and as follows:

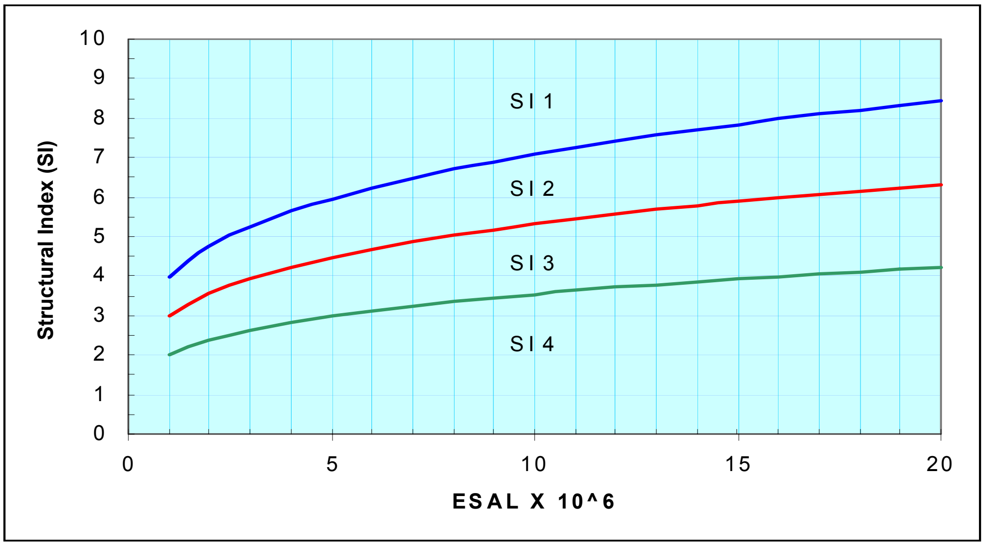

Figure 1 shows the classification with respect to bearing capacity (VVMB114).

$$\varepsilon_a = 37.4 + 0.988 \cdot D_0 - 0.533 \cdot D_{300} - 0.502 \cdot D_{600}$$

$$SI = \frac{1000}{\varepsilon_a}$$

Where ε_a is the tensile strain at the bottom of a bituminous layer in microstrain, and D_0, D_{300} and D_{600} are deflections at 0,300 and 600 mm from the centre of loading plate.

Table 8 Structural Index values

Target value	Bonus	Penalty	Rejected
	20 SEK/m²	20 SEK/m²	
85% ≥ SI 1-1 (=4.2) AND 100% > SI 2 (=3.9)	85% ≥SI 1+1 (=6.2) AND 100% >SI 1 (=5.2)	85% ≥SI2 (=3.9) AND 100% > SI 3 (=2.6)	15% < SI 2 (=3.9) OR SI value < SI 3 (=2.6)

2. Performance requirements and bonus/penalty values at year 7.

Table 9 Rutting

Target value	Bonus		Penalty		
	5 SEK/m²	10 SEK/m²	5 SEK/m²	10 SEK/m²	20 SEK/m²
8 mm	4-6 mm	<4 mm	10-12 mm	12-15 mm	15-17 mm

Table 10 Longitudinal profile, IRI

Target value	**Bonus**		**Penalty**	
	5 SEK/m²	**10 SEK/m²**	**5 SEK/m²**	**10 SEK/m²**
1.6 mm/m	1.20-1.40 mm/m	<1.20 mm/m	1.80-2.00 mm/m	2.00-2.20 mm/m

Table 11 Crossfall

Target value	**Bonus**	**Penalty**	
	2 SEK/m²	**2 SEK/m²**	**5 SEK/m²**
0.5 %	<0.4 %	0.6-0.9 %	0.9-1.2 %

Table 12 Fatigue cracking

Target value	**Penalty**	
	4 SEK/m²	**10 SEK/m²**
Severity level 1 (disconnected hairline cracks in <20% of surface area)	Severity level 2 (hairline cracks in 20-50 % of surface area)	Severity level 3 (cracks in >50% of surface area)

Skid resistance
Friction coefficient must be greater than 0.5 according to test method VVMB 104.

Raveling
Wearing away of the pavement surface caused by the dislodging of aggregate particles.
Target value is that raveling should be less than 20 percent of the surface area.

Bearing capacity
The bearing capacity evaluation performs as at the opening of the road but without regulation of any acceptance requirements. This is for future experience.

Comments to the case study
It should be mentioned from the above case that the agreement between client and contractor is based on various performance parameters (material, structural and surface parameters) for example pavement layer characteristics, which are wear resistance and water sensitivity determined on cores at the opening of the road. Construction requirements through bearing capacity determined by FWD and surface characteristics such as evenness, rutting, cracking and crossfall should be achieved by the in-service pavement after seven years of traffic.

Evaluation of function-based mixes

The first asphalt mix based on functional contract laid in west of Sweden was laid in 1991 and the contract was among the first of its kind in Sweden. Table 13 shows a summary of asphalt concrete contracts which have been used in this evaluation [Asp 2003]. Only objects which have elapsed several years are included in this evaluation even if the volume of contracts based on functional properties has increased with time. This evaluation is only the first part and it is based on rut depth development. Evaluations based on other functional properties are planned in addition to the socio-economical evaluation based on life cost analysis.
The rut depth development has been one of the most usual requirements in function-based contracts at least at early 1990s. Figures 2 and 3 show the rut depth development over time of SMA asphalt concrete layers carried out according to functional contracts. A general relationship for SMA mix based on recipe contract over same elapsed time is also shown in the figures 2 and 3.

Table 13 Summary of function-based contracts

Object name	Period Years	No of years	Max. allowable rut depth, mm	Measured rut depth, mm	Bonus/Penalty SEK/m^2	Bonus/Penalty SEK*10^3
Råda-Landvetter	91-94	3	5	5	0	0
Karlstad-Alster	91-94	3	7	5.8	7.7	402
Långås-Tvååker	92-97	5	12	4	24.1	1300
Jörlanda-St.Höga N	90-00	7	12	5.3	40.3	1450
Jörlanda-St.Höga S	93-00	7	12	5.5	40.3	1450
Tingstadstunneln S	93-00	7	14	10.7	19.8	258
Tingstadstunneln N	93-00	7	14	13.5	19.8	258
Viskan-Frillesås	95-00	5	7	2.7	5.5	251
Torpa-Fjärås	95-00	5	7	2.7	0	0
Kungsbacka S-C	95-00	5	7	3.9	1.5	27
Varnhem-Våmb	95-00	5	5	3.2	4.6	498
Arendal norrut	94-01	7	11	6.7	14.2	510
Arendal söderut	94-01	7	11	5.5	14.2	510
Kareby-Jörlanda	94-01	7	11	7.9	11.7	490
Frillesås-Viskan	96-01	5	7	5.2	9.4	386
Dönstorp-Simmatorp	94-02	8	7.5	3.9	7.3	2100
Karlstad österut	97-02	5	7	6.8	4	387
Karlstad västerut	97-02	5	7	6.3	4	387

The relationships for function-based SMA mixes are presented per road objects. It is obvious that the function-based SMA mixes show smaller rut depth development over time than recipe based SMA mix. There is also a tendency that the function-based SMA mixes have improved (lower rut development) at recent years compared to early 1990s when the use of performance based contracts started.

In average the rut depth developments for motorways with the recipe based SMA and function-based SMA are 1.04 mm/year respectively 0.69 mm/ year. See Figure 2. The service life of asphalt concrete with function-based SMAmix has increased by 33 %. However, the construction cost for Road Agency has increased in average by 12 SEK/m^2. For the main arterial roads presented in Figure 3, the service life of the asphalt concrete with function-based SMAmix has increased by 29 % in respect to recipe based mix. The construction cost has increased by 6 SEK/m^2. So far it is concluded that there are a lot of advantages in using function-based contracts and that the functional contracts imply lower costs per year. A whole life cost investigation is ongoing with the intention to clarify the effect of function-based contract on the cost of pavement. These conclusions are also in agreement with conclusions reported by Nordic Road Association – Committee 33 [NVF 1998].

General comments

In general, the Swedish performance specification is a combination of performance and performance-based specification in addition to the traditional approach (recipe specification). The Swedish specification gives high degree of freedom under condition that client and contractor come to an agreement. The procedure is relatively simple, useful and practical, but it still needs a lot of development to be a complete performance specification. It is also concluded that there is a lot of advantages in using function-based contract and the functional contracts imply lower costs per year.

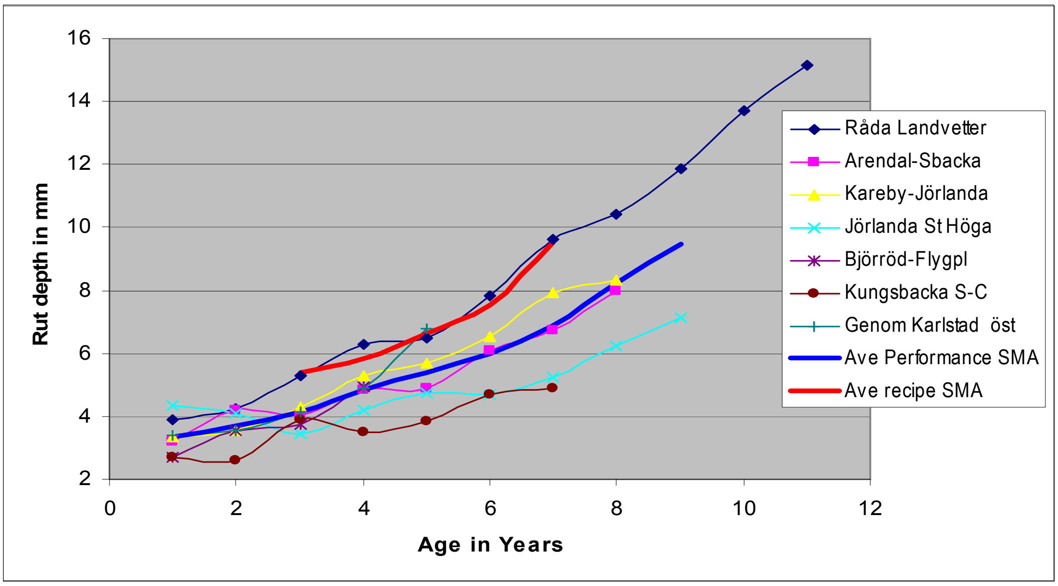

Figure 2 Rut depth developments for motorways with an AADT close to 10,000 vehicles per lane.

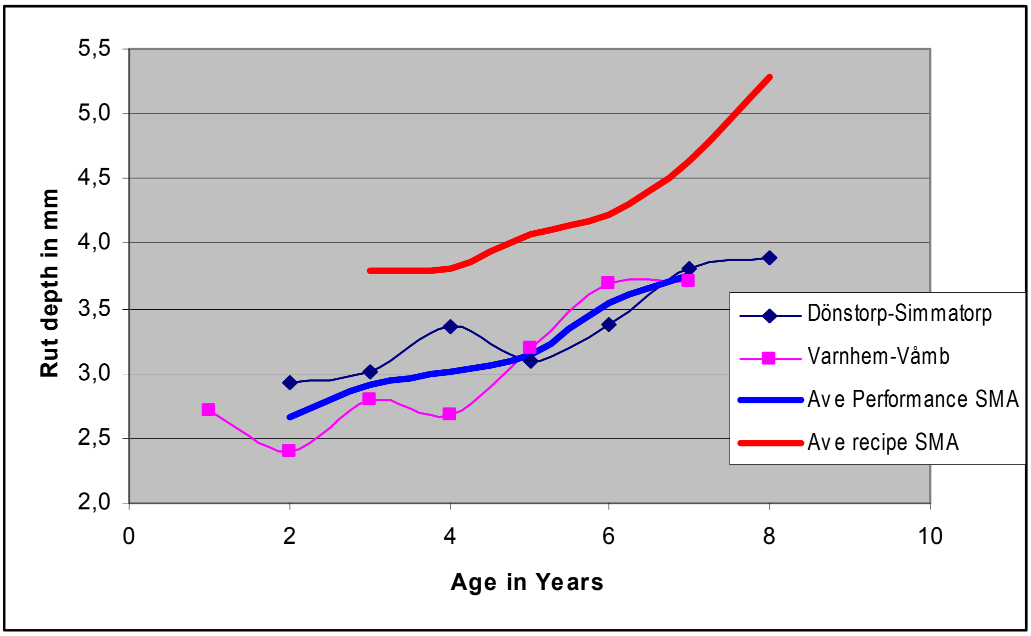

Figure 3 Rut depth developments for main arterial roads with an AADT close to 4,000 vehicles per lane.

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