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Reliability Analysis of Switches and Crossings – A Case Study in Swedish Railway

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A B S T R A C T

It is reported that switches and crossings (S&C) are one of the subsystems that cause the most delays on Swedish Railways while accounting for at least 13% of maintenance costs. It is the main reason for choosing to base this study on this subsystem.
Intelligent data processing allows understanding the real reliability characteristics of the assets to be maintained. The first objective of this research is to determine the S&C reliability characteristics based on field data collection. Because field failure data are typically strongly censored, an especial statistics software package is developed to process field failure data, as commercial packages have not been found satisfactory in that respect. The resulting software, named RDAT® (Reliability Data Analysis Tool) has been relied upon for this study. It is especially adapted for statistical failure data analysis. In the next step the availability of studied switches and crossings is estimated based on the reliability characteristics founded in the first step.

1. Instruction

Railway is a complex system because it comprises a mix of components with different age and status that have to work together in a system. In addition, the replacement of components is also a continuous and ongoing process. Today the railway infrastructure, therefore likes a patchwork that has to perform to higher demands. Infrastructure managers must keep infrastructure highly available so that railway undertakings (train operating companies) can deliver a high quality service at affordable price to end users. Expected increases in traffic volume will impose higher utilization of existing capacity and reduce the time available for maintenance and unplanned interruptions. Maintenance must therefore be performed near capacity limits, time between asset renewals should be long enough to balance the maintenance and acquisition cost, and components should be replaced by deferred or planned maintenance. For this reason changes have to be carefully studied and executed. In summary, the key goal is to achieve availability target cost effectively, or to minimize life-cycle cost subject to availability constraints.

Availability itself is a function of reliability and maintainability of a system as well as the maintenance support. It implies that for achieving high availability we need to go through reliability, maintainability, product support and service delivery approaches. It is proposed to apply RAMS

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(reliability, availability, maintainability and safety) analysis along with advanced statistics and decision support techniques in order to address this need.

If maintenance is organized in such a way as to minimize equipment downtime, availability will be maximized and it will be possible to extract as much capacity as possible out of existing assets. Therefore, the goal of proposed study is summarized as: reliability analysis of railway switches and crossings – Case study in Swedish railway.

The study was conducted in two phases. The phase one was the choice of system to be studied and definitions. In this phase the definitions given accordingly are resumed. The second phase is the processing and analysis of field failure data and reliability analysis. The correct execution of the second phase is crucial which can be the start point and used in the later phases in maintainability and optimization.

The inputs for the phase two are failure data on railway switches at the representative time. In order to conduct this phase in a good way the different inputs should be available, including:

- Detail failure and maintenance recorded data
- Detail maintenance action done
- Mission profile, duty cycle and environmental characteristics

After receiving the data, it is analyzed with the RDAT (Reliability Data Analysis Tool) and trends were studied in order to fit the data in appropriate reliability distributions. The adequacy of the parametric curves also was tested with a goodness-of-fit test. After doing this it becomes feasible to give the following deliverables:

- Reliability model (as function of time) for the items of equipment under study
- Sensitivity of reliability to environmental and duty cycle parameters

As it is intended to use some concepts and terminologies in this paper, it’s better to have their standard definitions which are used in those meaning in the paper.

2. Definitions

2.1 RAMS

According to EN 50126, is an abbreviation describing a combination of Reliability, Availability, Maintainability and Safety RAMS analysis is a recognized management and engineering discipline for the purpose of predicting the specified functionality of a product over its complete life cycle.

2.2 Reliability

Is defined as the probability that an item can perform a required function under given conditions for a given time interval. The most essential figures of merit are: the failure rate λ, given in number of failures per unit of time or distance or per number of demands. The reciprocal of the failure rate is also used: the Mean Time Between Failures (MTBF) for repairable items (it is the case in the study). The mean time between failures is the average time the operator can use the equipment before it fails. The probability of survival R(t), given in percent. If the failure rate is constant, then [5]:

$$R(t) = e^{-\lambda} \quad (1)$$

2.3 Availability

According to IEC 50 191-11-01 is the ability of an item to be in a state to perform a required function under given conditions, at a given instant of time or over a given time interval and assuming that the required external resources are provided. There is no dimension for availability, rather it is a percentage. The definition of availability that is used for this study is the inherent availability. It is just taking into account the time of repair [9].

$$A = \frac{Total\ time - \sum times\ of\ repair}{Total\ time} \quad (2)$$

Where the total time is the period of use of one individual turnout (calculated by asset name) and Σtimes of repair is the sum of all the repair times of one individual turnout (calculated by asset name).

2.4 Switch and crossing

A railroad switch, turnout or set of points is a mechanical installation enabling railway trains to be guided from one track to another at a railway junction [3]. Below (Fig. 1) a representation of a switch and crossing is provided.

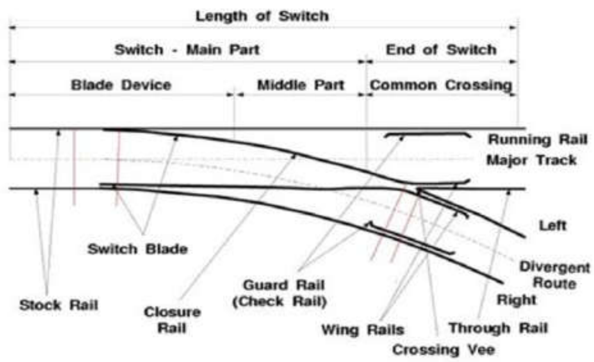

Figure 1: Schematic of a switch and crossing

In the Swedish railway system different types of switches and crossings are available. The name of a switch and crossing is composed by various parts i.e. A – B – C – D. Part A refers to the type of switch (single, double, etc.); Part B is the type of rail; Part C denotes the type of radius or length of switch blade and Part D states the type of angle. An example of such coding is EV – SJ50 – 11 – 1:9.

A switch and crossing is made by different subsystems as [8]:

- -Ballast -Rail
- -Check rail -Rail joint (mostly protected rail joint)
- -Cross over panel -Sleeper (bearer)
- -Crossing -Snow protection
- -Fasteners -Switch blade
- -Heating system -Switch blade position detector
- -Locking device -Switch device (motor, gearbox, coupling, bars, etc.)

3. Data collection and evolution

The preliminary obtained raw data was about 43528 failures registered for all the turnouts on the Swedish railway from January 2005 to December 2009. In order to use the data it is important to put them in the format that is needed. In this case it was necessary to adapt the data to RDAT software.

The first step is to filter the data to the types of turnouts that are in the priority list of interests. That means it was necessary to take out some types of turnouts data from the analysis, because there is not enough failure data since if they fail they won't be repaired but just replaced. The reason is that they are too old or located in places where there is not so much traffic to worry about. So the raw data were reduced by eliminating the types of turnouts with names including numbers inferior to 50. For example if for a type of turnout with the following name: EV-SJ43-….or EV-BV40… it was we eliminated. But, for a type of turnout with the following name: EV-SJ50… or EV-BV50… it was kept. This suppression of types of turnouts without interest for the study leads to the number of failures of: 42221. The second data cleaning was performed after the first one. It means that the data for turnouts which their installation dates was not defined were ignored and thereafter among the remaining data just the data which the turnout by itself was known was selected. It is important to mention that in raw data a lot of failures were not assigned to a particular turnout. It is the part of data that is called unknown (10477 failures). Finally, after filtering, sorting and modifying raw data the process ended up to study 29676 failures, which represent 68% of raw data (Fig. 2). In order to precise the study and reduce the amount of data by ignoring the irrelevant data it was decided to consider the tracks with more failures. Despite, taking into account just sixty tracks (out of 193) still a large amount of failures are explained.

Another focus was to reduce the data considering the ten types of turnouts (Fig. 3) that generate more failures.

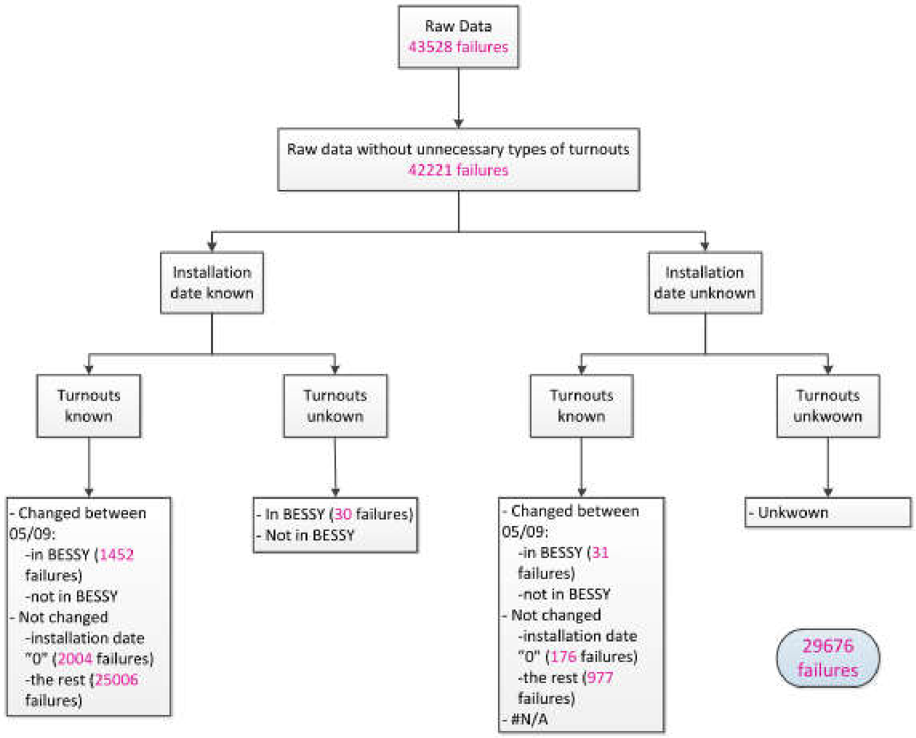

Figure 2: Data filtering process

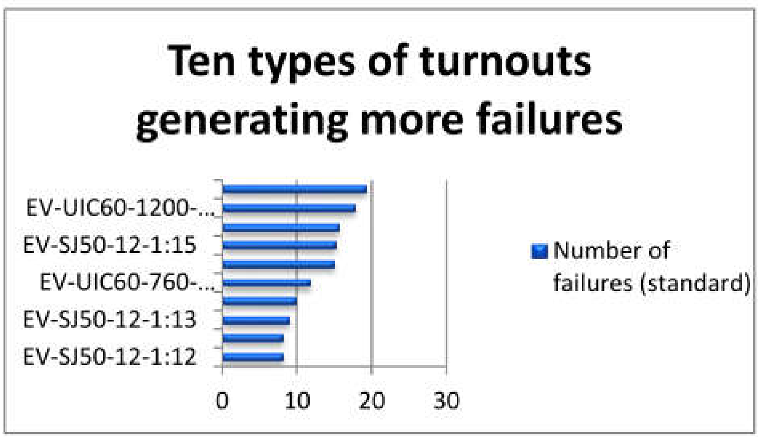

Figure 3: Bar chart of ten types of turnouts generating more failures

After these two focuses, both tracks and types of turnouts, at the end with 60 tracks and 10 types of turnouts 16627 failures (38% of raw data) can be studied.

Considering the fact that Sweden is a special country in the sense that there is a huge difference in weather conditions between North and South, classification in data was done taking into account the temperature factor. So it was decided to divide the data into two seasons, including the cold season and the hot season. The cold season is from November to March (both included), five month and the hot season from April to October, seven month. There is also another important factor which is the type of track. Nhsp is considering the main track and Ahsp is considering the diverging track. So, the data were separated by the type of the track as well.

Thereafter the data were classified by the track and the type of turnout. Sorting out by track, groups by region can also be made. This is the more precise step that is arrived to. To finish, the data that was implemented in RDAT software for definitive study the data for about 60 tracks and ten types of turnouts were considered. The software is not considering the data when there are too few failures. In fact for some groups only one turnout was affected and the software cannot do anything about it, just remove this data.

Considering the RDAT software limitations it was necessary as a restriction to focus on few tracks. It was taken into account that tracks with more failures are needed, with at least ten individuals by track and also at least two types of turnouts by track. Therefore, nine (9) tracks were chosen among the 60 tracks, which only 7 types of switches are existed (Table 1).

Table 1: List of existing turnouts

EV-SJ50-11-1:9
EV-SJ50-12-1:15
EV-UIC60-1200-1:18,5
EV-UIC6012001:18,5BL33
EV-UIC60-300-1:9
EV-UIC60-760-1:14
EV-UIC60-760-1:15

Some of the switches in Table 1 in turnouts group reduced to the following groups due to the similarity in designs as follow:

SJ50-11; SJ50-12; UIC601200; UIC-300 and UIC-760. These restrictions will conduct to more reliable results. The 9 tracks chosen are the following ones (Table 2):

Table 2 List of 9 tracks chosen

Track number	Type of track
124	Freight track
410	Commuter trains and some freight
414	Mixed passenger and freight
420	Mixed passenger and freight
512	Mixed passenger and freight
611	Mixed passenger and freight
811	Mixed passenger and freight
813	Mixed passenger and freight
912	Mixed passenger and freight

These 9 tracks at the different parts of Sweden (Fig. 4) are explaining 2566 failures out of the 16512 failures which were for 60 tracks and the 10 types of turnouts.

As mentioned before, even if the cold season has 2 months less than the hot season, the repartition of failures is 10% more during the cold period. The weather effect is a random factor that is affecting much more in the cold period. This reason may be one explanation of the fact that cold season contains more failures.

In Figures 5&6 the subsystems affected during cold and hot period are presented.

With taking into account the first four subsystems that are most affected it is noted that they are the same for both seasons. But it can be observed that during the cold period the heating system is much more affected than in the hot period. This is logical, but the difference is quite big meaning 1194 for the cold period whereas 120 for the hot period. For both seasons the subsystems known most affected are the switch blade position detector followed by switch device. In Figure 7 the number of failures for both seasons for the more affected subsystems are presented.

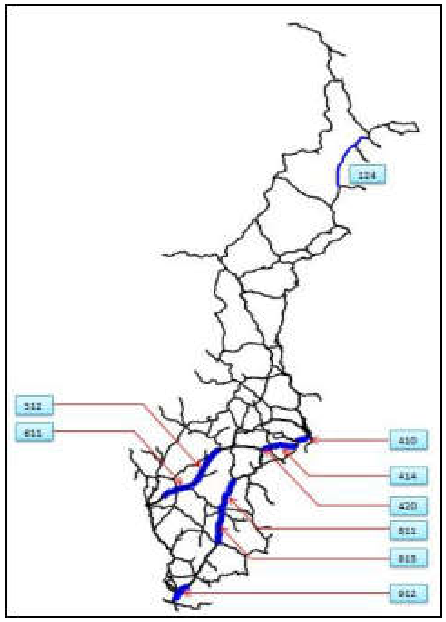

Figure 4: List of 9 tracks situated in Sweden

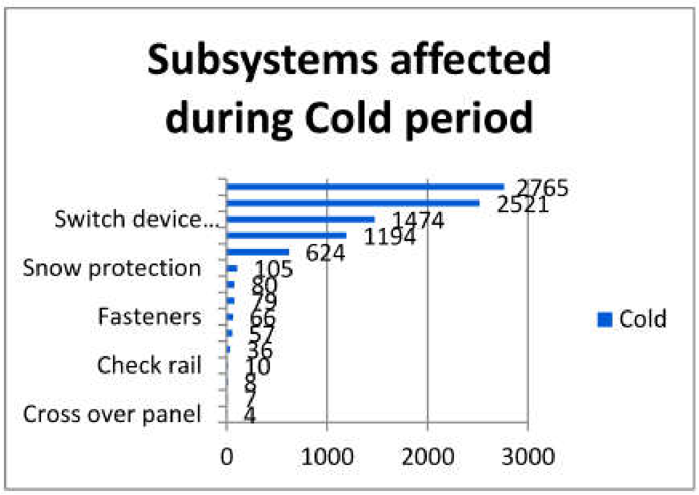

Figure 5: Subsystems affected during cold period

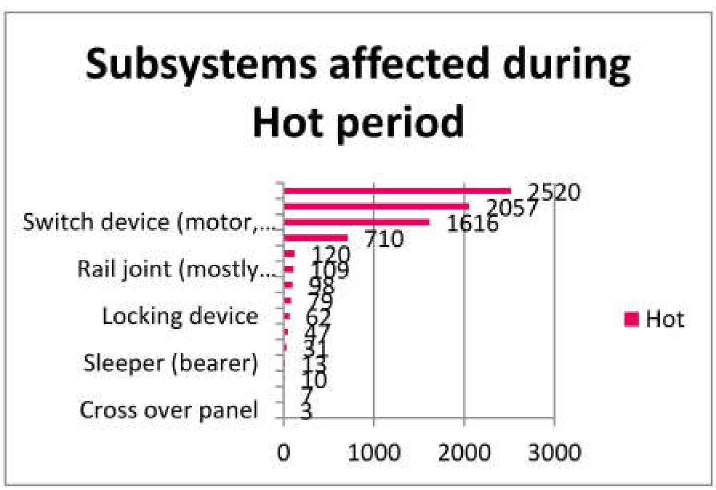

Figure 6: Subsystems affected during hot period

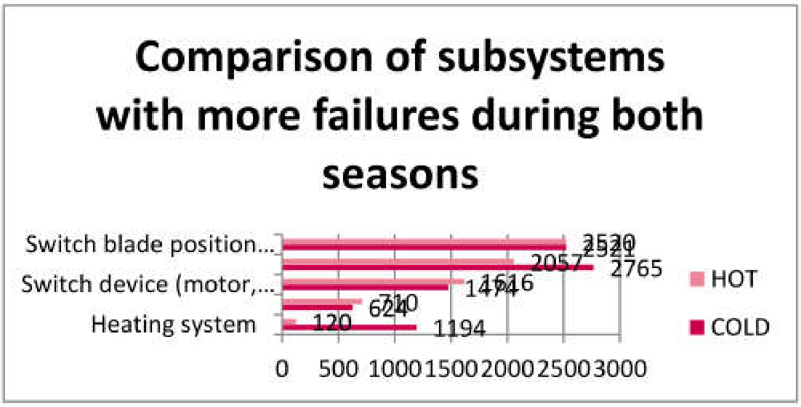

Figure 7: Comparison of subsystems with more failures during both seasons

4. Operation of RDAT software

The RDAT (Reliability Data Analysis Tool) software was developed by Alstom and the University of Bordeaux (France). This statistical data processing tool was developed in order to estimate the reliability functions and failure rates from field data, to test statistical trends and to quantify the influence of environmental and mission profile factors on reliability. This program was created few years ago because in the Reliability field it was needed in the sense that common programs weren't taking into account the data as they should. Highly censored (censored data are data that correspond to incomplete observations, that means that not all members of the observed population have had a failure over the period of observation) field data wasn't taken into account properly with the already existing programs.

Four failure models have been implemented in RDAT: exponential, Weibull, normal, and lognormal distributions. To select the best model, a goodness-of-fit test is applied.

The goodness of fit of a statistical model describes how well it fits a set of observations. Measures of goodness of fit typically summarize the discrepancy between observed values and the values expected under the model in question.

We also determine the quality of the maintenance based on the Kijima model [4]. The quality of maintenance can be affected by several factors such as different mission profiles/temperatures. The maintenance quality is measured by a parameter denoted Rho, which can vary between 0 and 1 as follow:

$\rho = 1$ means that the maintenance quality is AGAN (As Good As New), i.e. that the maintenance operation brings the item back to a reliability level corresponding to age 0 (the maintenance operation is perfect).

$\rho = 0$ means that the maintenance quality is ABAO (As Bad As Old), i.e. that the maintenance operation just allows the mission to continue but leaves the item with a reliability corresponding to the age accumulated so far.

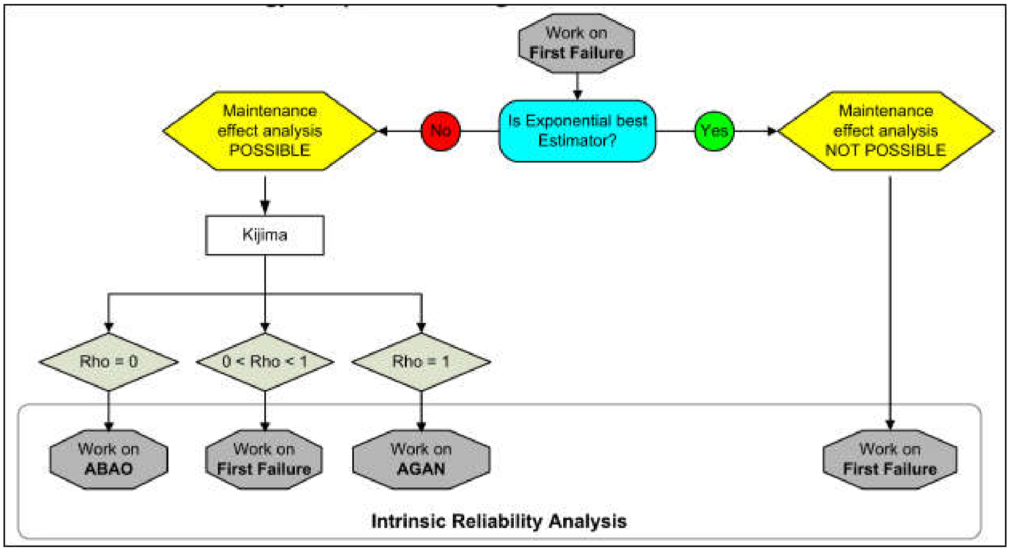

Figure 8: Summary of RDAT software's methodology

5. Data analysis – RDAT software output

The first data set that is put into the RDAT software as inputs was the data of the sixty tracks and ten types of turnouts generating more failures after the first phase of data cleaning (29676 failures). The calculation of the Kijima was made in order to find the quality of maintenance. The Kijima factor (ρ) analysis allows the characterizing maintenance efficiency. In 70% of the cases ρ was found equal to 1, and in 30% of the cases, equals to 0.5 or 0. This implies that in the majority of cases the maintenance can be considered AGAN. However, Trafikverket (Swedish Railway Administration) maintenance experts know that this is not the case, and their knowledge thus led to favor an ABAO model instead [7].

Therefore, the Crow-Amsaa [1] model was used to characterize the reliability function of turnouts studied. In this model the instantaneous failure intensity is obtained as:

$$\lambda_i(t) = \lambda \cdot \beta \cdot T^{\beta-1} \qquad (3)$$

and the cumulative failure rate is accordingly given by:

$$\lambda_C = \lambda \cdot T^{\beta-1} \qquad (4)$$

The instantaneous Mean Time Between Failures is given by:

$$MTBF(T) = \frac{1}{\lambda_i(T)} \qquad (5)$$

For each parameter a confidence bound has been estimated, using the chi-square test (with a confidence level of 80%, which this value is the common used value for confidence level because it is not only too restrictive but also not too wide). Details about estimation of Crow-AMSAA parameter model are:

Failure Rate estimation:

$$\hat{\lambda} = \frac{n}{T^{\beta}} \qquad (6)$$

Beta estimation:

$$\beta = \frac{n}{n \cdot \ln T - \sum_{i=1}^{n} \ln T_i} \qquad (7)$$

6. Results

Table 3 represents the output for shape parameter (as an indicator failure rate behavior) for different switches and different seasons. In the hot season and for main tracks the percentage of beta upper bound superior to 1 is on average 95.5% and for cold season is 6

Table 3: Growth factor Beta as a function of types of turnout and season and type of track

		COLD		HOT	
		% of β estimated > 1	% of β upper bound > 1	% of β estimated > 1	% of β upper bound > 1
ahsp	EV-SJ50-11-1:9	37,5	75	62,5	100
ahsp	EV-SJ50-12-1:15	100	100	100	100
ahsp	EV-UIC60-300-1:9	100	100	100	100
ahsp	EV-UIC60-760-1:15	100	100	100	100
nhsp	EV-SJ50-11-1:9	28,57142857	57,14285714	85,71428571	100
nhsp	EV-SJ50-12-1:15	14,28571429	57,14285714	85,71428571	100
nhsp	EV-UIC60-1200	55,55555556	77,77777778	88,88888889	88,88888889
nhsp	EV-UIC60-300-1:9	66,66666667	66,66666667	66,66666667	88,88888889
nhsp	EV-UIC60-760-1:15	43,75	75	81,25	100

Beta greater than 1 implies an increasing failure rate (or a decreasing MTBF). The maintenance is not compensating the age of the turnout. Old equipment fails more than a new one, which is logical when the quality of maintenance is ABAO (as bad as old). Beta lower than 1 implies a decreasing failure rate (or an increasing MTBF). This can be interpreted that the maintenance quality and actions may have been improved over these five years of study, or might the organization learned how to deal with failures. Another possible explanation could be that for the type of turnout SJ50-11, switch point detectors have been taken off (less failures detected) and for the rest of turnouts switch point detectors were changed from mechanical to electrical technology. This fact implies a lower detection of failures both in hot and cold periods.

Table 4 contains all the values of beta and lambda from the RDAT software for the nine tracks in detail.

An interesting graph(s) (Fig. 9 and 10) would be the failure rate as a function of time (5 years) but as the beta values are too different from one track to another for the same type of turnout it is a bit difficult to compare the curves. For one type of turnout and different tracks it is possible to see in a curve some increasing and some decreasing failure rates. However, it is difficult to adapt the scale.

It is important to remark that the failure rate during cold period is almost the double than in hot period. As an example Table 5 shows the failure rates for SJ50-11 for main track. The tracks of interest will be 124, 410 and 912. These tracks were chosen because the explanation of three situations is possible: beta near to one, beta lower than one and beta greater than one.

Table 4. Values of λ and β for different types of turnouts for the 9 tracks

	124		410		414		420		512		611		811		813		912	
SJ50-11	λ	β	λ	β	λ	β	λ	β	λ	β	λ	β	λ	β	λ	β	λ	β
ahsp - cold	2,4E-05	1,03497	0,0009	0,69615	0,00085	0,84745			0,00405	0,63068	0,02329	0,42709	4,1E-09	1,67594	0,00309	0,61334	9,7E-12	2,15507
ahsp - hot	0,00027	0,82694	2,9E-06	1,22332	7,6E-06	1,13605			0,00045	0,77678			1,4E-06	1,23256	3,3E-05	0,98722	3,5E-19	3,46262
nhsp - cold	0,00033	0,91207	0,0018	0,74697	0,0037	0,74645			0,01667	0,44456	1,1E-15	3,21404					0,01119	0,61563
nhsp - hot	3,2E-05	1,03756	9,4E-07	1,3985	1,9E-38	7,47652											0,0003	0,8702
SJ50-12																		
ahsp - cold			6,3E-10	1,89794									1,2E-07	1,67363				
ahsp - hot			5,1E-09	1,78155									8E-28	5,93182				
nhsp - cold	0,00085	0,85541	0,00188	0,742	0,02052	0,60981			0,00124	0,74185	6,8E-13	2,7261	0,00038	0,88729			0,00402	0,71
nhsp - hot	0,00019	0,96545	1,2E-06	1,28609	3,1E-05	1,01455			2,4E-10	1,93646	5,6E-15	3,08336	1,8E-10	2,01946			3,1E-05	1,03708
UIC60-1200																		
ahsp - cold																		
ahsp - hot																		
nhsp - cold			1,8E-05	2,45559			1,9E-06	1,50299	0,00063	0,83066	2,2E-17	4,77838	0,0002	1,99136	0,00076	0,84137	0,0142	0,56982
nhsp - hot			4,8E-33	6,27884					0,00185	0,74149			5,9E-05	2,2707	2,2E-05	1,06355	6,3E-08	1,50451
UIC60-300																		
ahsp - cold							2,3E-15	3,08952	1,1E-08	1,76695								
ahsp - hot							9,3E-37	7,39558										
nhsp - cold	0,0034	0,76851					3,5E-06	1,18365	0,01917	0,56181	1,8E-10	1,97927	0,02111	0,56799	2,6E-12	2,77407	4,4E-06	1,19847
nhsp - hot	0,00051	0,82548					2,4E-05	1,07717	0,00424	0,59919	6,9E-11	2,00702	0,00024	0,8705	2,9E-15	3,42747	2,9E-19	3,58544
UIC60-760																		
ahsp - cold																		
ahsp - hot									5,1E-06	1,33309								
nhsp - cold	0,00774	2,22288	0,00044	0,85533	0,01121	1,49191	4,7E-06	1,14619	0,01052	1,31048	3,4E-05	3,67323	1,3E-05	2,88129	0,00608	0,6835	0,00782	1,36585
nhsp - hot	3,4E-07	3,42084	6,4E-09	1,61714	1,8E-06	5,72424	0,00085	0,76081	3,9E-05	0,98111	1,9E-08	5,28677	0,00085	1,97365	2E-05	1,022	1,1E-05	2,49155

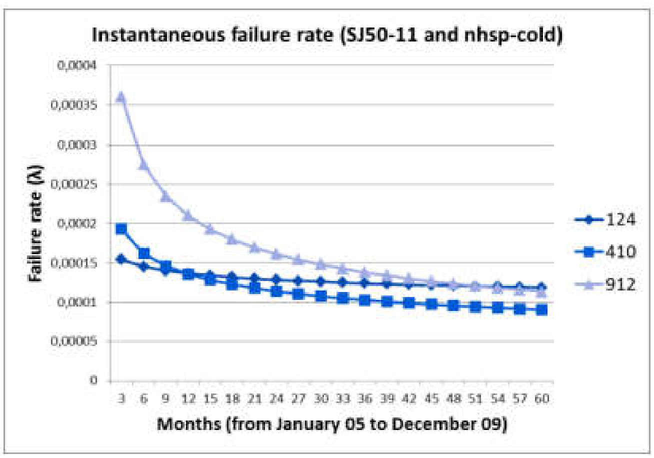

Figure 9: Failure rate of turnout SJ50-11 in different tracks in cold season

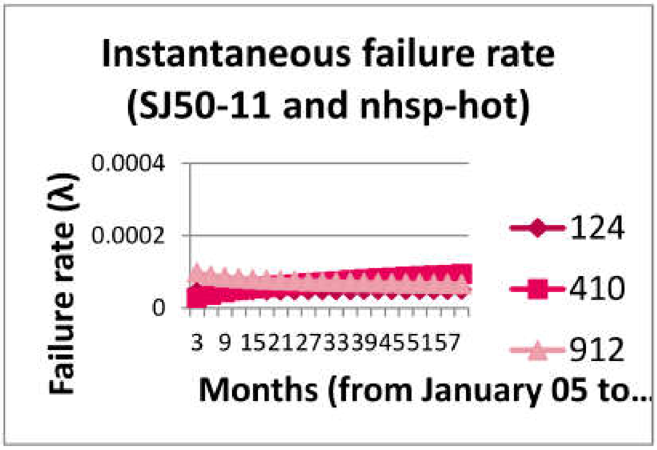

Figure 10: Failure rate of turnout SJ50-11 in different tracks in hot season

It is important to remark that the failure rate during cold period is almost the double than in hot period. As an example Table 5 shows the failure rates for SJ50-11 for main track. The tracks of interest will be 124, 410 and 912. These tracks were chosen because the explanation of three situations is possible: beta near to one, beta lower than one and beta greater than one.

Table 5: β and λ values for different tracks in different seasons

	124		410		912	
SJ50-11	λ	β	λ	β	λ	β
nhsp-cold	0,000332	0,912072	0,001805	0,746967	0,011192	0,615626
nhsp-hot	3,2E-05	1,037562	9,4E-07	1,398503	0,000304	0,8702

6.1 Availability calculation

The availability was calculated according to Eq.2 for each asset name (individual turnout). In order to have the availability by track it is important to understand that a track can be considered as turnouts in series, as shown in Figure 10.

It is needed to calculate the mean availability by track raise it by the number of turnouts on the track in order to have the availability by track. Table 6 shows the calculated values for availability for nine studied tracks. Track 512 has the lowest availability. The availability of this track is ≈45% when it has to be at least 98%. Tracks 811 and 611 have also low availabilities. It would be interesting to look to the maintenance on these tracks in order to figure it out what is happening.

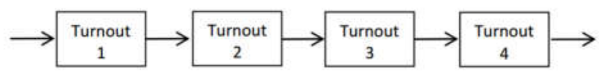

Figure 10: Schematic description of series turnouts system

7. Conclusions

Using field data from Trafikverket's databases into Alstom's software (RDAT) it is possible to obtain valuable information. One important parameter is the age of the turnout. The RDAT software is not taking into account this parameter. However, it is possible to do a covariate analysis including this factor.

As it's mentioned earlier, it would be interesting to explain how the maintenance is done in a better way. It is observed that during cold period there is much more β<1 than in hot period. This fact can be explained by better maintenance during cold period, but the question is how far this assumption is valid? Another observed fact is that track 512 has the lowest availability among the 9 tracks under study. Do we have to look more deeply on the maintenance in this track?

In addition, the first phase of the project confirms an increasing failure rate and some preliminary indications have been obtained on the most important failure contributors, which are the switch blade position detectors, switch devices, heating system in the cold season, and switch blades.

The wear rate (as measured by the Weibull shape factor) is rather low. This is not surprising in view of the fact that the data collected are data that reflect the maintenance policy, the goal of which is to postpone wear.

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Table 6: Availability estimation for studied tracks

Track number	Number of individuals by track	Mean Availability per turnout	Availability by track
124	56	0,9997	0,9818
410	64	0,9998	0,9851
414	44	0,9997	0,9884
420	21	0,9999	0,9974
512	91	0,9912	0,4483
611	32	0,9823	0,5645
811	64	0,9921	0,6004
813	60	0,9998	0,9906
912	65	0,9976	0,8565

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The authors would like to thank ALSTOM – France and Trafikverket – Sweden for their help and valuable support.

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