Component Reliability in the T-Book – The New Approach

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Abstract: T-Book is a reliability data handbook for use in Nordic Nuclear PSAs (Probabilistic Safety Assessments). Due to its ambitious scope, high level of detail, and high QA standard, it has become world-famous, and is frequently used even outside the nuclear field. Since 2008, Lloyd's Register Consulting, on behalf of the Nordic PSA Group (NPSAG) and TUD (the editor of T-Book), has performed a series of projects to enhance and consolidate the process, right from the classification and sampling of data, through parameter assessment, PSA modeling, and up to the final interpretation of results. Two aspects have proven to be of particular interest. Firstly, providing more homogeneous groups of T-Book components, which will have positive impact on PSA in terms of less conservative and more precise parameters, as well as increased consistency in the entire modeling process. Secondly, the benefits of said homogenization need to be weighed against the use of the multi-parametric model for standby components, because these two aspects are not fully compatible. A comprehensive approach, addressing both these aspects, is presented for selected components: pumps, batteries, diesel generators, and motor operated control valves. In this paper, the background and motives for the proposed strategy will be outlined, as well as the "tool box" to put it into practice. The presentation will also include what has been accomplished during 2013, and what is going to be introduced in the new version of the T-Book.

Keywords: Component reliability, T-Book

1. INTRODUCTION

The main objective of the T-Book [1], currently in the 7th edition, is to provide reliability data for the unavailability computations that are made for each component that is considered in the compulsory probabilistic safety assessments (PSA) of nuclear power plants. Safety, reliability and availability of nuclear power plants (NPP) are of paramount concern to employees, power companies, authorities and the public at large. As the use of PSA is wide in the normal safety work at the NPPs, there is a need for easily accessible and reliable failure data.

The failure characteristics presented in the T-Book are primarily based on the failure reports stored in the central database TUD (managed by the TUD Office) and the Licensee Event Reports delivered to the Swedish Radiation Safety Authority (SSM). The TUD database was started already in the middle of the 1970s, quite voluntarily by the Swedish power companies. In 1981, the Finnish power company TVO, operating two reactor units of Swedish design, joined the data collection system. Before the TUD data are statistically treated they are carefully examined with respect to consistency and correctness. The T-Book comprises only critical failures, i.e. failures that stop the function of components or lead to repair. The release history of the T-Book is outlined in table below.

Table 1: T-Book history

Version	Year	Comment
1	1982	Operational statistics from 21 reactor years
2	1985	Operating data covering about 40 reactor years
3	1992	Data up to the operating year 1987 included (108 reactor years)
4	1994	Data up to the operating year 1992 included (178 reactor years)

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Table 1: T-Book history

Version	Year	Comment
5	2000	Data up to the operating year 1996 included (234 reactor years)
6	2005	Data up to the operating year 2005 included (315 reactor years)
7	2010	Data up to the operating year 2007 included (378 reactor years)

As the amount of data has increased with each successive edition of the T-Book, continuous work has been done to improve the methods for the statistical inference and related tools required to derive the reliability parameters from the operational data in the database.

Already in the initial edition there was a Bayesian reasoning in the description of the uncertainty associated with the failure rates or demand-related failure probabilities. Analytically attractive distributions, gamma distributions for the failure rate, were used to model this uncertainty, and straightforward statistical methods were used to estimate the parameters of these distributions.

2. SUMMARY OF PREVIOUS WORK

As mentioned in the introduction there has been a continuous work to improve the methods and tools used to derive the reliability parameters in the T-Book. Since 2005 a series of such projects have been launched starting with a master thesis [4] with the purpose to study the mathematical model used in the T-Book and to compare it with other models. This has been followed by a series of additional works, in several cases in the form of master thesis's (see references [5], [7] and [8]). A brief summary of this previous work and the conclusions that were derived upon which has led to the work that is currently ongoing is given in the subsections below.

2.1. Study of the statistical methods used in the T-Book

The two-stage Bayesian method that is used in the T-Book today was studied in the master thesis work presented in [4]. The Bayesian method has been specifically developed for the T-Book and is particularly appropriate when data is extremely sparse. One objection against it however, is that it is somewhat non-transparent and therefore it may be worth studying if it could be simplified or even replaced by a simpler alternative, if there is one.

On this basis alternative methods were studied in the thesis work and an alternative Finnish method developed by Jussi Vaurio was identified an interesting alternative to study further. The main advantages with this alternative method would be fast calculations, transparent mathematical expressions and straightforward replication. Moreover, the numerical results presented in the thesis looked quite promising. Hence, though further comparisons were deemed to be necessary, this alternative method was proposed as a simpler and in some respects even better alternative to the method used in the T-Book. Even though the thesis pointed out this specific alternative method the work conducted after the thesis has not been focused on this alternative will is shown further on in this paper.

2.2. Test and analysis of homogeneity

The first master thesis, see [4], was followed by a second master thesis [5] which had the purpose to study homogeneity. The two-stage Bayesian method used in the T-Book comprises an assumption of inhomogeneity among the components of a population which is different compared to how it is done in the German ZEDB framework [9]. If components are assumed to be inhomogeneous it is possible to assign a specific failure rate for each individual component. On the other hand, if the components are assumed to be homogeneous the data can be pooled before a common reliability parameter is derived representing all components in the group. The objective with this thesis work was to design a statistical method for testing the homogeneity of Nordic data with emphasis on their failure rate. A *chi-square goodness-of-fit test* with consideration taken to operation time (or standby time), was implemented and applied on failure event data for the Nordic utilities.

From the tests it was concluded that the failure intensity for continuously operating components for most populations can be considered homogeneous with regard to failure rate. However, the test results also indicated that populations of standby components are to a larger extent inhomogeneous, which might be explained by differences in the data set due to unequal number of demands. It was also concluded that larger populations, i.e. components of all plants, must be considered as more inhomogeneous. Furthermore, it was recommended in the thesis work that a statistical test of homogeneity should be introduced.

2.3. Pros and cons using a using a multi-parametric model

As a result from the two master thesis works mentioned above additional work has been performed, which was presented at PSAM11 in Helsinki related to pros and cons with the $q_0+\lambda t$ model [3] and evaluation of grouping criteria [2]. The conclusions presented in [3] are briefly summarized here.

One of the conclusions was that the T-Book approach deviates from what is state-of-the-art internationally in using a two-parametric model for assessment of reliability parameters of standby components. The principal merit of the model is that it is intuitively attractive because standby components are naturally associated with two different failure mechanisms. The $q_0+\lambda t$ model estimates parameters representing these two mechanisms statistically from a joint data set. Thus, the type of failure does not have to be determined beforehand. Instead, the correlation between the two parameters is derived by virtue of the different activation intervals that are present in a group of components. Nevertheless, two major challenges were pointed out related to this model:

- The study shows that pooling of data (i.e. summarizing failures and exposure time, respectively, for components in the same group) has positive impact on PSA in terms of increased precision, decreased conservatisms, and improved conditions for implementation of parameters. However, the $q_0+\lambda t$ model uses differences between individual components thus implying that data cannot be pooled.
- It was also pointed out that it has been questioned if it is possible to apply a multi-parametric model in an industrial field where data are generally sparse, which is challenging even for single parametric models.

Thus, to keep the $q_0+\lambda t$ model, it was concluded that it has to be stated that its advantages are overriding the advantages of pooling data, and that the model is well suited for the area of application.

2.4. Evaluation of grouping criteria

The second topic that was addressed in the continuous work, and which is described in [2], was an evaluation of grouping criteria. The results to date, as described above and documented in [5] show that pooling of data (i.e. summarizing failures and exposure time, respectively, for components in the same group) has positive impact on PSA in terms of increased precision, decreased conservatisms, and improved conditions for implementation of parameters. However, pooling of data requires the component groups to be homogeneous, which has not been verified for the T-Book. Thus, alternative grouping criteria have been studied.

One such alternative is the so called function oriented criteria used in the German PSA community (represented by VGB, RiSA and the ZEDB software). This criterion is assumed to result in homogeneous populations, thus strengthening the motives for data pooling. It was then concluded that application of these criteria requires splitting up today's groups based on attributes like water chemistry, operational conditions and a finer division of quantitative variables. It was furthermore recommended that statistical tests should be used to verify homogeneity for the groups obtained.

It is therefore assumed that alternative grouping criteria, together with homogeneity tests, will considerably enhance the quality and usability of reliability parameters for PSA.

3. HOMOGENEOUS GROUPING OF COMPONENTS

A pilot study was performed [6], driven by previously performed work [2], with the purpose to evaluate the conditions for adoption of the grouping criteria used within German ZEDB into the TUD framework (i.e. the TUD database, T-Book, as well as underlying classification principles and routines). One underlying concern here was that application of current T-Book distributions is restrained because they are derived component-wise and then weighed together plant-wise. Such parameters are not well suited for PSA since neither parameter sampling nor event sampling will be fully applicable. Event sampling might be the more reasonable approach; however it may yield non-conservative results, dependent on the structure of the model. Moreover, there might be parameters from other sources in the model that shouldn't be event sampled (wherefore parameter sampling is the default approach in e.g. RiskSpectrum®).

The main objective of the work described in [6] was to evaluate the possibilities of adopting the ZEDB grouping strategy into the TUD framework and to benchmark current groups and attributes, as well as structures and purposes of the databases used. On the basis of this benchmark, the scope and objectives to fully apply the ZEDB grouping strategy to pumps in the T-Book was outlined. The benchmark was carried out in close dialogue with the TUD office and RiSA (developer of the ZEDB software).

ZEDB is an MS-Access based software used to store and process failure data from 21 nuclear power plants: 19 German, 1 Dutch and 1 Swiss. Integrated with the database are modules for validity, consistency, and homogeneity checks, as well as for computation of reliability parameters. As in T-Code (the software used to derive the reliability parameters in the T-Book), a two-stage Bayesian model is used (this is sometimes referred to as a "super-population approach") [9]. A large part of the information in [6] is related to describing the ZEDB and the T-Book classification frameworks and it is pointed out that the following general conditions have to be fulfilled when putting data together in the ZEDB framework:

- Components in the same group have to have a similar function.
- There has to be a sufficient amount of operational data for the components.

Up to 2004, sets of components in the ZEDB framework were defined using the technical descriptors of the components. Pump sets were then established using "pump type", "pump drive" and "fluid" and then clustered by nominal discharge head and nominal mass flow rate. As from the ZEDB Analysis of 2004, the sets have been split into smaller groups according to their function, thereby strengthening the motives for assuming homogeneity. This enhanced grouping strategy was first applied to pumps and has been applied to other component types in the subsequent issues of the ZEDB Analysis report from 2006 [9]. However, since data is more or less sparse, it is not always possible to derive function oriented groups. Thus, for some pump types, group populations are still used. Group populations and function oriented populations are thus coexisting although the latter is the ideal. Group populations thus represent the old scheme and are used as a secondary choice if no function oriented population is available for the component at issue. Only functional oriented populations are mutual exclusive.

The TUD database contains information on approximately 600,000 components whereof 23,000 of these are represented in the T-Book with reliability parameters for use in PSA. As in ZEDB, a component is defined as a functional part of the plant and a variety of attributes can be registered for each object. However, none of these attributes are used in queries to define the component groups. Component groups only exist in T-Book, each corresponding to a certain T-Book table which is directly connected to the relevant object ID codes via the event records. These groups have been established beforehand in an expert eliciting process which was originally carried out at the prospect of the first issue of T-Book in 1982. At the prospect of the fifth T-Book in 2000, the pump groups were revised and adjusted to the ICDE CCF database project. The revision resulted in new categories with respect to flow and pump head. Furthermore, BWR and PWR components are not separated but may be referred to the same group dependent on the attributes. Since the attributes are not used in queries, they are not mandatory in the database, but allowed to have a varying degree of completeness. Hence, if components are to be reclassified according to a new set of attributes the TUD database is probably not sufficiently detailed, whereas plant databases should be.

As previously mentioned, the work described in [6] also included a benchmark of the function oriented pump groups in the ZEDB Analysis of 2006 [9] and the T-Book version 6 [10]. The main purpose with this benchmark study was to see if the ZEDB grouping criteria could be used also in the T-Book for justification of homogeneity assumption. Thus the important questions were:

- Do the groups match?
- What is making the difference?
- Is it possible to overcome discrepancies?

As a rule, the groups match quite well, although with three main sources of mismatch which need to be dealt with. The differences identified relate to either differences in design or population mismatches where some systems are not separated in the T-Book as they are in ZEDB or a system is divided into subgroups in ZEDB but not in the T-Book. Furthermore it was concluded that the T-Book need to separate strictly between BWR and PWR components in order to be able to utilize the ZEDB grouping criteria. The differences identified was however judged to be manageable and it is noted that the aim here was not to copy the ZEDB scheme but to obtain credible grouping criteria for the T-Book and to be able to verify these against ZEDB groups.

It is also noted in [6] that a re-grouping of T-Book components implies a reduction in the T-Book populations and there is therefore a risk that data is lost. It is at the same time noted that this is exactly the reason why function oriented groups have not always been possible to establish in ZEDB. However, the T-Book comprises more historical data which may compensate for this along with the fact that the T-Book comprises fewer plants compared to ZEDB.

Based upon the conclusions from the pilot study [6] the work has continued with studying the pump populations in the T-Book [11]. The purpose of this work has been to develop function oriented grouping criteria that can be used for regrouping of the pump populations used in the T-Book and to perform statistical tests that will verify that the new groups are homogeneous. The basic assumption that was applied was that the new groups shall be considered to be homogeneous if the opposite cannot be demonstrated by statistical methods.

In order to achieve the function oriented groups the five criteria listed below were used where the third criteria (medium) was added to the already existing grouping criteria in the T-Book, since water chemistry is judged to be of importance when it comes to component reliability (e.g. due to corrosion and wear). Other modifications have also been made to the existing grouping criteria.

- Type of plant (BWR or PWR)
- Type of pump
- Medium distributed by the pump (de-ionized water, contaminated water, sea water, borated water, oil)
- Operational mode (in operation, in stand-by or intermittent operation)
- Mass flow
- Pump head

The test method that was applied measures if the component failures (e.g. spurious stop) are evenly distributed over the group population over time. The hypothesis to be evaluated in this case was that all components within the group could be represented by the same failure intensity. Based on empirical data a test variable (Q) was defined and compared against a critical value. If the test variable is greater than a given critical value then the hypothesis about homogeneity is rejected and the group is considered as being inhomogeneous. The test variable Q, often referred to as *goodness-of fit*, is defined according to Equation (1).

$$Q = \sum_i \frac{(Q_i - E_i)^2}{E_i} \tag{1}$$

Where:

Q_i: Number of observed failures for pump i.
E_i: Number of expected failures for pump i.

Assume that a group consists of i pumps with the same constant failure intensity for a given failure mode. Further assume that the variable Q_i can be described by a Poisson distribution, see Equation (2), and that this would render in a total number of N failures during time period T. If those assumptions are valid, the number of occurred failures would be distributed according to Equation (3) (Multinomial distribution).

$$\langle Q_i \rangle = E_i = \lambda t_i \tag{2}$$

$$P(O_1 = n_1, O_2 = n_2, \dots, O_N = n_N) = \frac{N!}{\prod_i n_i} \prod_i \pi_i^{n_i} \tag{3}$$

Where: $$\pi_i = \frac{n_i}{N} = \frac{t_i}{T} \tag{4}$$

$$\sum_i n_i = N, \sum_i t_i = T \tag{5}$$

Then the expected number of failures E_i is given by (6):

$$\pi_i N = \frac{N}{T} t_i \tag{6}$$

A Monte Carlo technique can then be used in order to simulate the expected distribution of Q given N and the cumulative distribution of Q (CDF(Q)) can be generated. The observed number of failures (q_s) is significant, i.e. the group is inhomogeneous if the probability of getting a value that is higher than q_s is small, which has been defined as less than 5% as shown in equation (7). The method is exemplified below.

$$P(Q > q_s) = 1 - CDF(Q = q_s) < 0.05 \tag{7}$$

Assume that we have two recorded failures in a group of four components according to table below.

Table 2: Example of operational experience

Component	**No. of failures**	**Time in operation**
A	2	100
B	0	100
C	0	100
D	0	200

The simulated distribution and the Chi2 distribution are illustrated in Figure 1. The result based on the multinomial distribution is that the observations for the four components are homogeneous with a confidence of >95% (1-CDF(Q = q_s) = 0.119). On the other hand, the result based on the Chi2 distribution indicates that the components are inhomogeneous (1- χ_3^2 (Q = q_s) = 0.046). This discrepancy can be explained by the fact that Q cannot be approximated with a Chi2 distribution based on such sparse data. If the number of observed failures would be six, instead of only two, then the result would be as illustrated in Figure 2 in which the Chi2 distribution is a better approximation of the multinomial distribution.

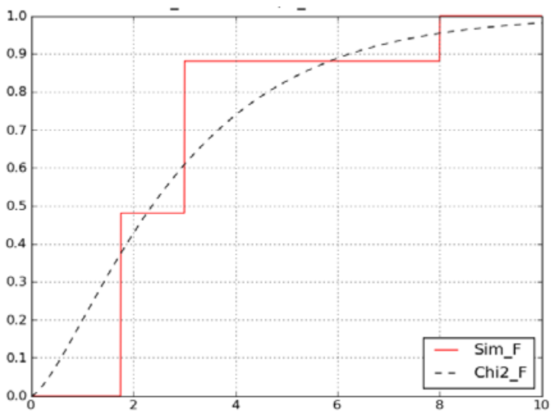

Figure 1 – Example where red line equals 1-CDF(Q) and black line equals $\chi_3^2(Q)$. *No. of simulations are 100.000.*

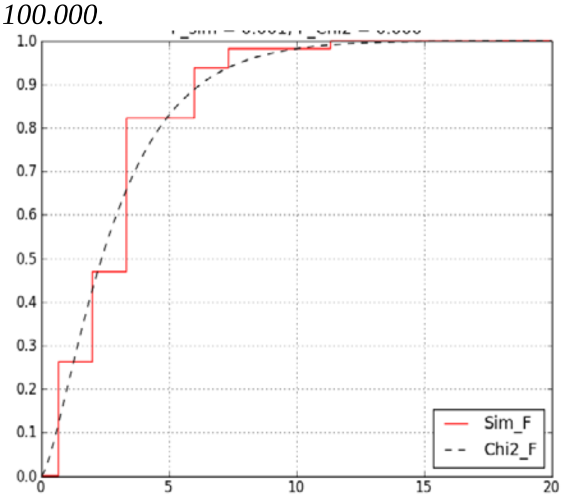

Figure 2 – Result of the example with six observed failures instead of two. Red line equals 1-CDF(Q) and black line equals $\chi_3^2(Q)\,\chi_3^2\;(Q$.

Based upon what has been presented above, new pump component groups have been defined compared to current version of the T-Book (version 7, [1]) and these are suggested to replace the existing component groups since all but 1,5% of the groups have been demonstrated to be homogeneous, i.e. the variation between the likelihood of pump failure is small within each group. It is also recommended that data within each group is pooled, i.e. super components should be created for the groups. This is judged to have a positive effect on the PSAs that use the failure data in the form of more precise estimations, decreased conservatism and more consistent treatment of uncertainties, since parameter sampling can be used for uncertainty analysis in the PSA model. There are however some exceptions where it is recommended that the current strategy used in the T-Book is kept, i.e. without pooling of data.

In a similar way as for the pumps work is currently ongoing in defining new groups for batteries, diesel generators and valves.

4. MULTI-PARAMETRIC MODEL FOR STANDBY COMPONENTS

Since the 3rd version of the T-Book (1992), the so called $q_0+\lambda t$ model has been used to estimate failure probability for stand-by components. In this model, q_0 is derived from failures occurring at the time of demand while λ_s characterizes failure mechanisms that are active during the standby time. In reference [2], as has been described earlier, this methodology has been evaluated and the conclusions as presented in [2] are that the model does not work in a satisfactory manner for several of the component groups. The main reason for this conclusion is due to lack of support in the data, i.e. sparse data. It was also demonstrated that the model gives about the same results as the simpler λt model when the amount of data is sufficient. For some component groups, a constant failure probability, q_0, can be assumed to represent the dominating contribution to the component unavailability estimation, and it was concluded in [2] that it is important to identify these component groups.

As a result of the above presented conclusions from [2], one part of the work in producing version 8 of the T-Book is to develop evaluation criteria that will support deciding which component groups should be evaluated with the $q_0+\lambda t$ model and which should be evaluated using either λt or q_0. The purpose of the work presented in [12] is to evaluate and present selection criteria to facilitate this choice and to plan how the selection will be carried out during the implementation phase. The method should be able to demonstrate to what degree the data from experience supports the use of the multi-parametric model $q_0+\lambda t$.

The approach that was used in [3] has been used in order to evaluate and verify the use of $q_0+\lambda t$. An important aspect to consider is that the sought after criterion is based on a technical, physical or functional basis in order to be unbiased with regard to specific data. In [3] it was found that component test interval is of importance in order to demonstrate the validity of using $q_0+\lambda t$ and this parameter can therefore be used as an independent variable during the search for the criteria in question.

All stand-by components were analyzed and compared using the methods presented in [3] (version 6 of the T-Book), the data however was updated to reflect the most recent version of the T-Book [1]. The hypothesis was that the more data the more obvious it would be to identify common patterns. Therefore, based upon the conclusions from [3] the process to verify the use of $q_0+\lambda t$ involved the following steps:

1. Based on the given data; calculate λ_s' using the $\lambda_s t$ model and q and λ_s'' using the $q+\lambda_s t$ models.
2. Determine the difference $y = \Delta Q$ between the unavailability calculated using the different data settings

$$\Delta Q = \frac{Q_\lambda - Q_{q+\lambda}}{Q_{q+\lambda}} \tag{8}$$

Where:

$$Q_m = 1 - \frac{1}{\lambda_s \cdot TI}(1-q)\left(1-e^{-\lambda_s \cdot TI}\right) \tag{9}$$

for $Q_m = f(\lambda_s' t)$, then $y = 0$

TI is represented by the groups average test interval since this is when the models are considered to be comparable, as illustrated by the red circle in Figure 3.

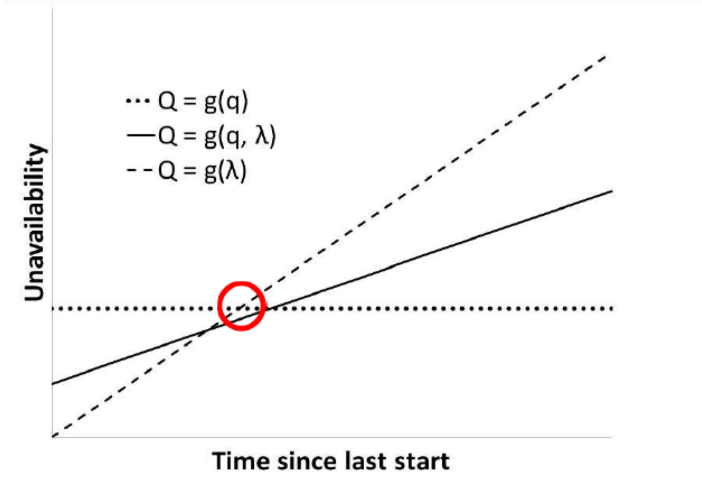

Figure 3 – Intersection between the curves described by each of the models q, $\lambda_s t$ and $q+\lambda_s t$.

The next steps are to:

3. Calculate $y = q/Q$ for the components. This function describes the contribution from q to the total unavailability.
4. Plotting of $y = \Delta Q$ and $y = q/Q$ respectively against the deviation in TI^* where TI^* is the true "actual" test interval, i.e. the quote between number of activations (planned and "spontaneous") and the time in stand-by for each component in the group. This test interval is what is being used in the calculation algorithm T-Code which is used in the T-Book.

Several different measurement of deviation can be used during interpretation of the plot. Standard deviation (average deviation from the mean value) for a groups TI^* can be used but since standard deviation is sensitive to extreme values ("outliers") another type of measurement should also be used, e.g. the median deviation MAD (Median Absolute Deviation).

$$MAD = median_i\left(\left|X_i - median_j\left(X_j\right)\right|\right) \tag{10}$$

In a comparison when different measurements of deviation are used, deviations in data can be explained, e.g. a component group seems to have a large deviation but is nevertheless not analyzed satisfactorily using $q+\lambda_s t$. The explanation for this can be that one or some components in the group significantly differ from the other components and those components give rise to an increased mean value at the same time as the other components in the group are allowed to have a very similar test interval. In these cases the measurement of variation is not valid since it measures a behavior that is reflected by data not supported by the used model. The work presented in [12] used both standard deviation and MAD for this purpose.

Figure 4 shows plotting of $y = \Delta Q$ against standard deviation in TI^* and therefore demonstrates the difference in percentage between Q_λ (unavailability using $\lambda_s t$ model) and $Q_{q+\lambda}$ (unavailability using $q+\lambda_s t$ model) as a function of TI^*.

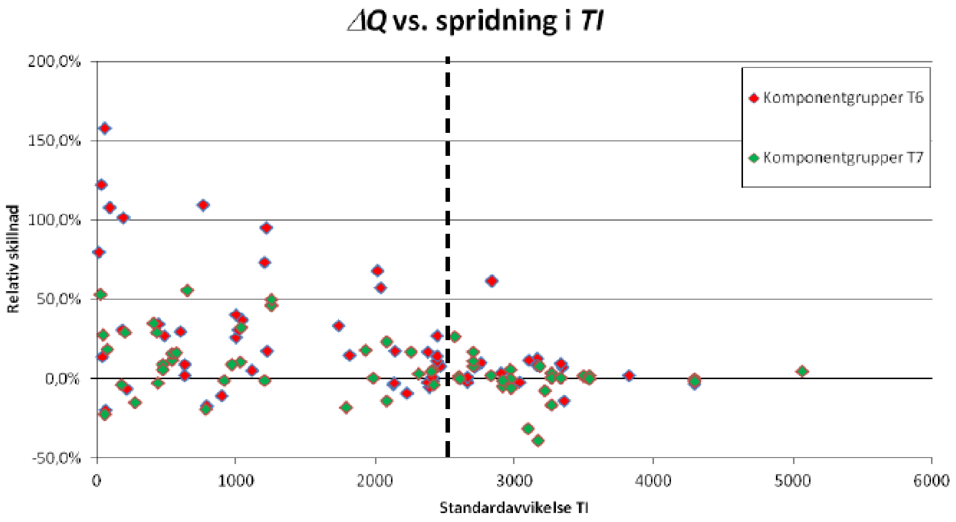

Figure 4 –T-Book tables evaluated by ΔQ as a function of deviation in TI. ΔQ expresses the difference between Q calculated with the q+λst model and the λst model, respectively. Thus, a value of 0 % implies that the two models yield identical results, a positive value that the q+λst model yields a larger Q than the λst model, and a negative value that λst yields the higher Q.*

The result pictured in Figure 4 implies that the smaller the spread in *TI**, the larger Δ*Q* will be, i.e. with a minor deviation, *q*+λ*st* is overestimating the unavailability. The most probable explanation for the picture is that with less information the hyper-prior used in the Bayesian update has greater impact on results. This hyper-prior is to be updated with data, i.e. if there are few data points, e.g. small deviation in *TI**, the hyper-prior will remain affecting the result to a considerable extent. However, *Q* is not overestimated for all tables. Some of the tables in the left region have a Δ*Q* near 0%, and sometimes it is even negative. This might be revealing an inconsistency in the updating of the hyper-prior, i.e. in the numerical algorithm that is pacing around the "rough estimate of central point" to find data supply. This conclusion is supported by the convergence of $Q_{q+\lambda s}$ and $Q_{\lambda s}$. Moreover, the convergence of $Q_{q+\lambda s}$ and $Q_{\lambda s}$ might be due to a successively decreasing contribution from *q* with increasing amount of information available. This was analyzed through plotting the ratio of *q* to $Q_{q+\lambda s}$ against the deviation in *TI* as presented in Figure 5.

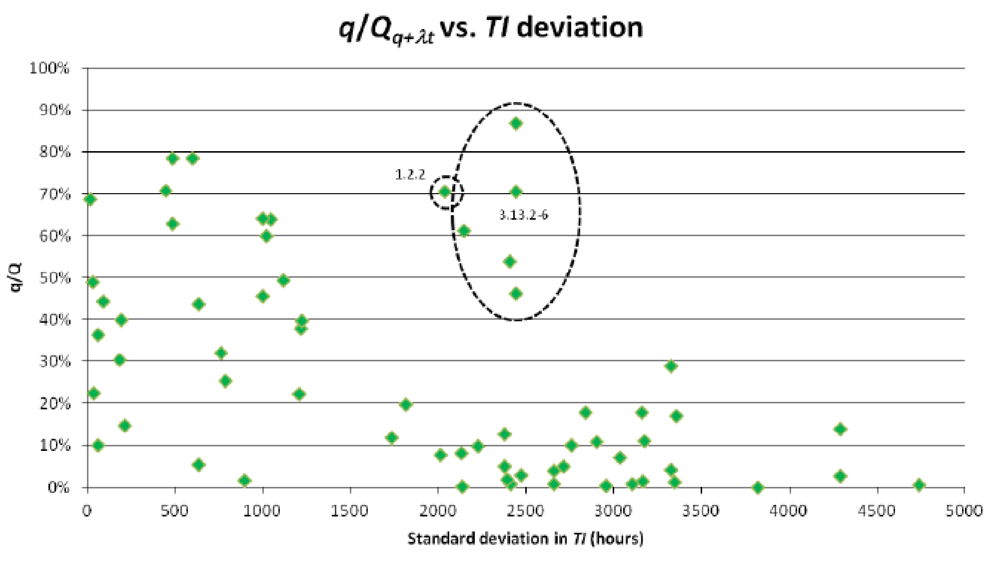

Figure 5 – q/Q as a function standard deviation in respective component groups test interval where each dot represents a table in the T-Book, i.e. a failure in a stand-by component)

The plot of $y = q/Q$ in Figure 5 shows a general tendency of large q for small deviations in TI^* and that the importance of q gets less the larger the deviation is. This can also explain why the more supporting data there is, the smaller ΔQ gets (q a-priori is large, which overestimates $Q_{q+\lambda}$ but the more data there is available the more precise the estimation will get). However, the fluctuations in ΔQ for small variations in TI^* cannot be explained by a large q. These fluctuations are more likely due to numerical problems (instability) when data is sparse. It can also be noted that in some cases q gives a large contribution even for components where the amount of supporting data is larger.

The procedure is then repeated using MAD instead of standard deviation and the resulting plots looks quite similar. The results imply that the $q+\lambda_s t$ model is working when the deviation in TI^* is large, which is logical. It is however not apparent when it starts to work satisfactorily. The dashed line in Figure 4 represents an attempt to make such a distinction. It shall also be noted that when the deviation in TI^* is large ΔQ gets smaller, i.e. it is not important which model is used. The simplest solution may therefore be to use the simplest model, $\lambda_s t$, for all components. However, the importance of q does not vanish completely and for some groups it contributes significantly. Therefore the conclusion is:

> **The $q+\lambda_s t$ model shall be used in the range where it can be proven to work and for component groups where the importance of q is significant.**

6. CONCLUSIONS

The work performed in this paper is significant progress in terms of the quality of the data presented in the T-Book. However, even though it might seem to be rather straightforward there are, and will always be, considerations that need to be taken into account, such as:

- Is it possible to establish a clear and definitive criterion that supports the choice of which method to use for deriving failure probability q and intensityλ?
- Can it be demonstrated that the $q+\lambda_s t$ model is suitable to use even though this will mean that it will not be possible to pool data? For component groups with sparse data this means that the benefit of pooling can be greater than the benefit of using $q+\lambda_s t$ model.
- Can it be demonstrated that the reliability data derived is not optimistic for all components?

For the time being it seems that a systematic process where different aspects are being tested from case to case, and from T-Book to T-Book (new versions), is the most suitable way to progress. Work is currently ongoing regarding redefining the component groups in coming version of the T-Book and to apply the different tests outlined in this paper in order to decide what model to use. In the coming version 8 of the T-Book the plan is to have two parallel versions (old and new methodology), but in future versions the old approach will be phased out.

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