

# Determination of Target Reliability Levels Based on Value to the Customer and Warranty Budgets

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**Abstract:** The method presented here serves to determine the system's as well as subsystems' target reliability levels combined. It centers the functions of the product to be developed and knows to weight requirements in line with the voice of the customer. Each subsystem's target reliability level is defined in accordance with its quantitative contribution to fulfilling the functions as desired by the customer. Statistically inevitable failures before the targeted product lifetime are often compensated by warranty and good-will expenditures. These costs are methodologically broken down and allocated to each subsystem purposefully in order to achieve the utmost customer satisfaction. By bringing together such costs per subsystem and its importance to the customer, reliability goals are obtained aligned with the value to the customer.

In contrast to most of the existing methods to define and allocate reliability goals (typically realized by two different methods), subsystem target reliability levels are defined at first. The system's reliability goal is then calculated by means of Boole-theory. Arbitrarily complex systems can be analyzed.

**Keywords:** Reliability Allocation, Reliability Optimization, Reliability Goal, Target Reliability Level, System Reliability

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## 1. INTRODUCTION AND MOTIVATION

Reliability engineers are often called upon to make decisions on the product's goal reliability [1,2]. The question of how to meet this goal leads them to a reliability allocation problem. Which component needs to perform how reliably in order to meet the system's reliability goal and assure an economically competitive development at the same time?

A given product can be considered as a means of providing the functionality meeting the customer's needs. In these terms, the task of product development is to design the product so that it is able to perform its functions reliably. However, not all components of a given system need to be equally reliable. Neither do they contribute to a given function equally nor are the functions equally important. The omnipresent economical constraints in competitive environments require the development to allocate resources in line with the customers' requirements.

Product reliability has repeatedly been specified as the most important order winning criteria for complex products [3]. It seems reasonable to integrate the customers' voice into the determination of the product's reliability level.

In an effort to achieve the utmost customer satisfaction, statistically inevitable failures before the targeted product lifetime are compensated by warranty and good-will whose costs commonly make up about 10% of the company's turnover, i.e. about as much as the targeted profit margin [3]. To let reliability goal determination emerge from given warranty-related expenditures is therefore logical.

As will be discussed, the process of determining a system's goal reliability and allocating subsystem reliability goals is currently a two-step process. First, the system's goal is determined for which cost considerations often serve as the basis (cf. Chapter 2.1). The system's goal is then broken down into goals for each subsystem (cf. Chapter 2.2). Established methods do not merge the two steps into one.

Another reoccurring problem is the requirement of various factors which are empirically determined. Furthermore, the customer's point of view is hardly incorporated in neither the system's nor the subsystem's goal reliability determination. The customers' requirement regarding the functions of the product are not adequately taken into account either.

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## 2. STATE-OF-THE-ART

Section 2.1 outlines current best practices for defining a system's reliability level. In sections 2.2., the most common methods for deriving target reliability levels of subsystems from the system's reliability goal are briefly reviewed in order to analyze what they have in common and what they lack, whereupon the problem description and motivation for the proposed method (cf. Chapter 3) is based.

### 2.1. Methods for defining system reliability goals under financial considerations

Different methods exist which aim at optimizing the relationship between costs and reliability levels. They help at defining economically sensible reliability goals. The most common methods for defining the system's reliability goal are listed in Table 1 [4].

**Table 1: Overview of Approaches Optimizing Reliability Levels Under Financial Considerations**

Approach by	Characterization
Selivanov	Product costs over the useful life (including maintenance costs)
Churchman	Maintenance costs with interest and acquisition costs
Brunner	Product costs under consideration of MTBF and the minimization of reliability levels
Köchel	Maximizing system reliability by means of redundancies
Kapur	Effort minimization algorithm
Kohoutek	Reliability costs as the sum of costs of development, manufacturing and warranty costs
Schnegas	Costs and reliability in the context of product definition

The approach by Selivanov considers the total costs of a technical product over its useful life and herein includes investment costs, costs proportional to the operating time as well as costs increasing with operation time (e.g. maintenance costs). This approach lacks the possibility to be used in early development stages as the two latter costs cannot be defined until well into the useful life.

Churchman takes into account initial costs as well as maintenance costs including interest. Here again, the connection to reliability is only given through maintenance costs, which have to be known. The reliability structure is not considered.

The approach by Brunner is based on finding the cost-optimal mean time between failures (MTBF) [5]. Considered costs are product costs in general as well as maintenance costs. The formula includes costs dependent on (desired) reliability levels. The determination of some needed factors requires expert knowledge which limits its application.

Köchel suggests a method to determine the financially optimal number of redundant identical subsystems. Apart from the redundancies, the product's reliability structure has to be serial. The method is suitable for early development stages.

Kapur's method requires an effort minimization algorithm which aims at minimizing the development effort by means of optimal component reliability levels. The definition of a threshold reliability level for each subsystem is the basis for deciding whether or not the individual reliability level needs to be improved. The reliability structure has to remain serial. Hartig [5] describes how such an effort minimization algorithm can be implemented and points out limits to the method.

Kohoutek's method is the only one which explicitly incorporates warranty costs. Costs of reliability also comprise costs of reliability design as well as costs of reliability in manufacturing, for which an empirical function needs to be defined. Practical applicability is limited due to the lack of the required quality function [4,5]. Furthermore, the product's reliability structure is not incorporated in the model.

Schnegas [4] describes a model according to which the material costs of a unit are calculated as the product of the volume and a cost-factor. Similarly, manufacturing costs are calculated. By comparing load levels to the geometry withstanding the load, reliability relevant information is obtained since stress levels relate to reliability and geometry relates to costs. [4,5,6]

## 2.2. Methods for allocating subsystem reliability goals

Two groups of methods can be distinguished: unweighted and weighted methods. Table 2 summarizes the most common methods.

**Table 2: Overview of Approaches Apportioning Reliability Levels to Subsystems**

Approach by/ name	Characterization
Equal Apportionment	Unweighted method. Each subsystem is assigned with the same reliability level.
AGREE	The importance of the subsystem to the system is considered in terms of its contribution to the total time of application.
ARINC	New failure rates are calculated based on pre-knowledge and the assumption that their share toward the system reliability remains the same.
Feasibility of Objectives	Empirically determined factors weigh the contribution of a subsystem to system reliability.
Karmiol	Empirically determined factors weigh the contribution of a subsystem to system reliability, consideration the subsystems' functional importance.
Bracha	Factors calculated based on partly empirically determined parameters weigh the contribution of a subsystem to system reliability.
Mettas	Based on the monetary effort to improve existing subsystem reliability levels, new goal reliability levels are derived for each subsystem.

### Unweighted Method

The Equal Apportionment method allocates subsystem reliability targets assuming equal failure rates for each subsystem leading to the given system reliability level [7]. It is the most simple of all allocation methods. The system reliability needs to be known, the failure rates of all components are assumed to be constant (exponential failure distribution) and the system's reliability structure to be either completely serial or completely parallel.

### Weighted Methods

Weighted Methods share the commonality that they are able to derive subsystems' reliability targets more accurately from the known system reliability level than the unweighted method described above due to using weighting factors. These factors stem from different scopes of consideration. The input information can be known or assumed. Weighted methods are more realistic and therefore have higher practical relevance [6,7]. Like the unweighted method, the weighted methods have in common that the system's reliability level (i.e. target) is known up front, based on which subsystems reliability levels (i.e. targets) are allocated.

The AGREE Method considers the total number of subsystems ( $N_{AGREE}$ ) (1<sup>st</sup> tier) as well as the number of subsystems  $n_i$  within a subsystem (2<sup>nd</sup> tier) [6,7]. Since subsystems and sub-subsystems are considered in the calculation, the system's complexity is included in the derivation of the subsystems' reliability targets (1<sup>st</sup> tier). The importance factor  $E_{AGREE}$  incorporates the importance from a time input point-of-view for each subsystem, referenced to the total time of system application. All subsystems' failure distributions need to be exponential and the system's reliability structure to be serial.

The fundamental assumptions of the ARINC method are again, that the system is strictly serial as well as that all subsystem's failure distributions are exponential (i.e. have a constant failure rate) [7]. Additionally, the subsystems' failure rates need to be known (or assumed). Calculated are allowable failure rates  $\lambda_i'$  based on the system's new maximum allowable failure rate  $\lambda_{system}$  by means of weighting past failure rates  $\lambda_i$  of subsystems  $i$  to their sum (which equals the old system's failure rate). The per-cent contribution of the new failure rate to the new system's failure rate thus remains the same as before.

As for the Feasibility of Objectives method, each of the  $n$  subsystems' failure rate  $\lambda_i$  is the product of the system's failure rate with a factor, similarly to the ARINC method. The factor is the product of a set of four parameters which evaluate a given subsystem's complexity, state-of-the-art, operation time

and environment qualitatively in the range of e.g. 1 to 10 requiring expert knowledge. This method also requires the system to consist of serially connected subsystems with constant failure rates [4].

The Karmiol method allows for describing serial systems where individual components can have identical redundancies. The failure distribution has to be exponential, meaning that the failure rate is constant. Similar to the Feasibility of Objectives method, different factors are used which influence the allocation of reliability goals to subsystems: complexity, criticality, state-of-the-art and operational profile (i.e. operation time and environmental exposure). Again, they are evaluated qualitatively in the range of 1 to 10. Additionally, a subsystem's relevance in terms of the number of its functions  $F_i$  is considered.

Bracha's method assumes that four factors influence the reliability allocation to subsystems: sublevel complexity, state-of-the-art, environmental conditions and operation time. Failure rates need to be constant again. Kececioglu describes in detail how to determine the factors a, c, e, and t which relate to each other [7]. The Bracha method is also able to cover systems in which individual subsystems have identical redundancies similar to the possibilities of the Karmiol method (and practically all of the methods discussed, e.g. by summarizing redundant parts into one by means of Boole-theory). [6,7]

Mettas' method [8] takes into account the effort (i.e. costs) for achieving certain reliability goals and allocates them accordingly. Subsystem reliability levels need to be known. The method can therefore not be applied for the development of new products unless the factors can be estimated in a substantiated way. In an effort to find the financial optimum, the sum of reliability related costs has to be minimized. The method requires some heavy assumptions to be made, e.g. factor  $f$ , which stands for the feasibility of increasing the reliability of subsystem  $i$ . It influences the relationship between costs and achievable reliability levels (cf. [8]). Some important aspects are not covered by this method either, such as the operation time or the importance to the customer [6].

### 3. PROBLEM DESCRIPTION

Different methods exist for determining the costs of reliability efforts and some are even able to link the financial effort with actual reliability goals for the system (such as the model of e.g. Brunner, Kapur). Only one method takes into account warranty costs as reliability related costs (i.e. Kohoutek). Many consider MTBF (Brunner) or maintenance frequencies (Churchman) as the reliability goal striven for. Some are too general (e.g. Selivanov) while others are too specific (e.g. Köchel). Most require significant levels of expert knowledge to determine the factors needed (e.g. Selivanov, Kapur, Kohoutek, Brunner) and most are limited in terms of reliability structures as they are able to cover only serial or only parallel structures but no combinations. The methods by Selivanov and Churchman only incorporate the product's reliability through maintenance costs. Others (Brunner, Kapur and Kohoutek) require parameters which are hard to determine and often have to be estimated.

Similarly, the methods for assigning subsystem reliability goals have significant limitations. Almost all of the most common methods as discussed above are limited to either strictly serial or strictly parallel systems. They allow individual components to be redundant with the same component. The application of practically all weighted methods requires considerable knowledge for estimating the factors needed, which limits their application, especially in early development stages. The Mettas method additionally requires the subsystem's current reliability levels to be known (which makes it an optimization method rather than an allocation method).

The method by Mettas is the only one which is able to cover complex system structures and as well as the only one considering costs directly as a factor influencing reliability allocation (cf. [8]). Yet it does not incorporate an "importance factor" representing the customers' point-of-view (such as the AGREE method) [6]. All but the method by Mettas are only able to cover (sub)systems with constant failure rates. The unweighted method of equal apportionment is generally considered too imprecise [6] but may help defining first reliability values for e.g. the Mettas method.

Based on these shortcomings of the existing methods, the method proposed in this paper offers a widely applicable approach to quantify the system's and subsystems' reliability goals based on the value to the customer while at the same time considering financial constraints from the manufacturer's point-of-view. Its goals therefore are the following:

- Accounting for the “voice of the customer” to assure designing the product that the customer actually wants, i.e. customer-driven target definitions.
- Merging the two steps for finding subsystem reliability goals into one step in order to facilitate the application.
- Reversing the process: first, subsystem reliability goals are to be defined first which then lead to the system’s reliability level using the reliability structure (as this is more in line with the recommended process of product development where the product is developed based on the functions it is supposed to serve [7]).
- Putting the product’s functions into the focus.
- Allowing for all kinds of system structures (i.e. combinations of serial and parallel).
- Incorporating the system reliability structure from early on as it has significant influence on economical resource allocation.
- Being independent from certain failure distributions (allow for non-constant failure rates).
- Assuring a straight-forward application without heavily relying on the estimation of parameters
- Applying target costing principles for defining the reliability goals instead of cost-counting principles: the benchmark for the desired reliability levels beside the customer is the market. The manufacturer should be able to scale efforts accordingly (i.e. the “voice of the manufacturer”).

#### **4. PROPOSED METHOD**

In this chapter, the proposed method is described, starting with the assumptions taken as a basis. The flow chart (cf. Figure 1) will guide the reader through the method.

##### **4.1 Assumptions**

- a. The product is regarded as a means of providing the functions the customer wants.
- b. The maximum customer satisfaction is sought most economically.
- c. Field usage of the product is considered the most critical phase to both failure behavior and ultimately customer satisfaction. The definition of target reliability levels is therefore linked to warranty budgets.
- d. Budget allocation for the actual development of the product to the subsystems takes place in a separate step (not part of the proposed method; cf. e.g. [4,9]).
- e. Customers’ information on the desired functions is available or can be assessed.
- f. The warranty budget and time, the product’s parts list as well as the costs for rectifying a warranty claim are known.
- g. The basic requirements for applying the Boole-theory are met.

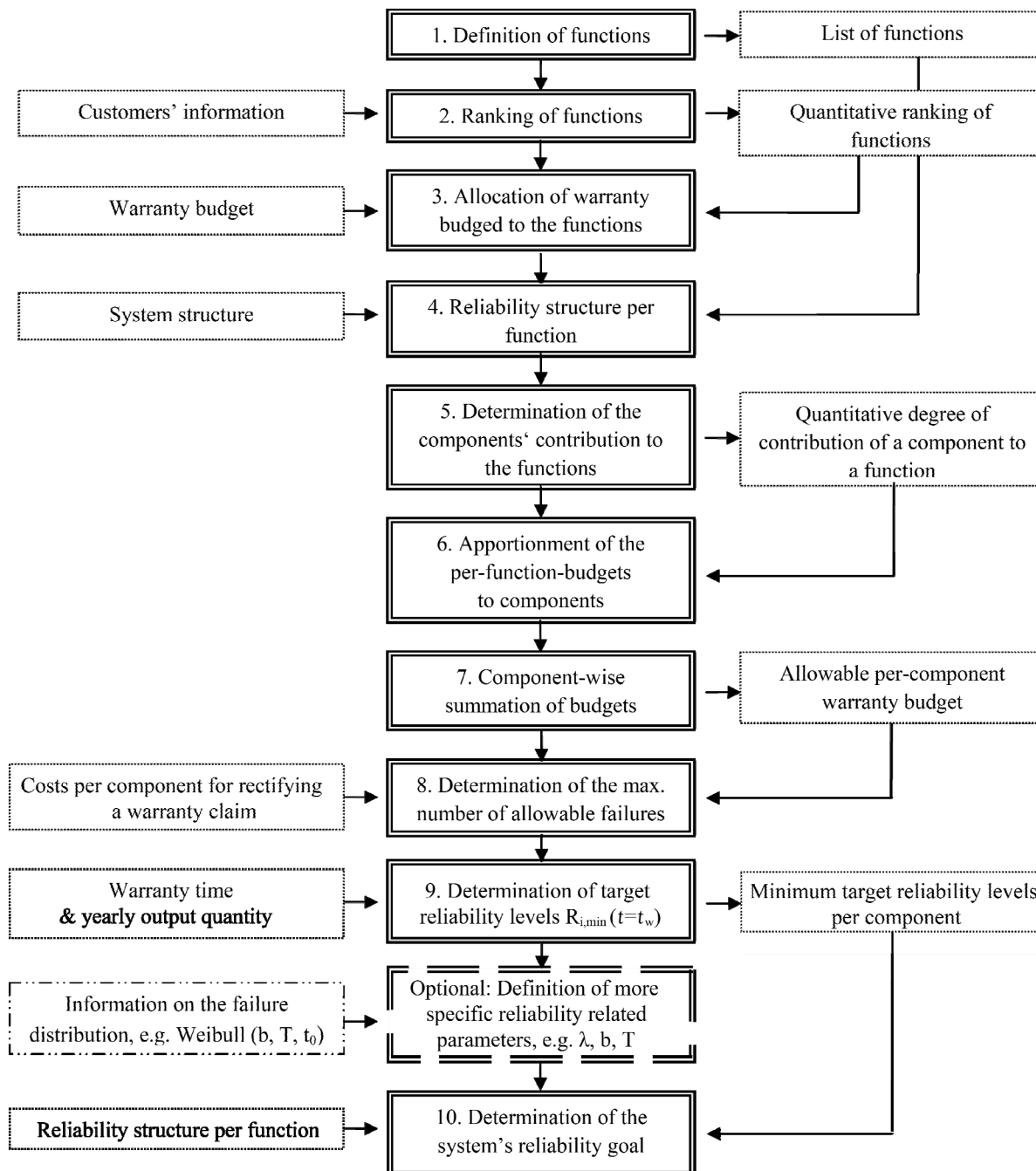
##### **4.2. Approach**

Figure 1 illustrates the different steps of the proposed method which are described in this chapter. Each step as indicated in the flow chart is described below.

Step 1: The product’s functions are defined and listed from the viewpoint of the customer and as input from development.

Step 2: The functions are ranked from the customer’s point-of-view, e.g. by means of a pair-wise comparison, an evaluation grid or others. The result is a quantification of the product’s functions’ importance to the customer in percent.

**Figure 1: Flow Chart of the Proposed Method**



Step 3: The importance levels are multiplied with the given warranty costs accounted for by product development, e.g. defined by means of target costing (benchmarking) or experience gained from previous products. The outcome is the warranty budget to be allocated to a given function in order to ensure the customer's requirements toward the function regarding reliability.

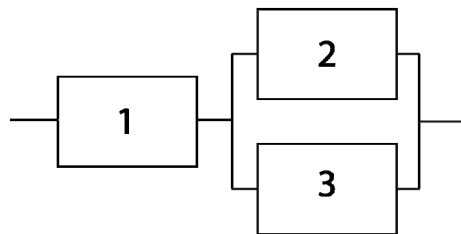
Step 4: A function is usually realized by several components interacting together. The system's parts list (considered as given) is mirrored according to the list of functions, e.g. by means of a matrix using a value managerial approach (cf. [10]). It can now be quantitatively determined how a component contributes to one or several given functions.

Step 5: Based on a component's position in the function-specific reliability structure, values are assigned to the different components function-wise. The value is one if the components are all in

series. If the system is composed of e.g. two components which are redundant to each other, the influence on the function is 0.5 (50%) each, if three components are redundant, the influence is 0.33 (33%) each etc.

For a system where component 1 is serial to two components 2 and 3 which are parallel (cf. Figure 2), the value would be 0.5 (50%) for component 1 and 0.25 (25%) for component 2 (cf. Table 3).

**Figure 2: Exemplary Reliability Structure for a Function**



**Table 3: Exemplary Determination of the Components' Contribution to the Function**

	Component			Sum of the influence
	1	2	3	
Influence on the function (absolute value)	1	1/2	1/2	2
Influence (per-cent value)	0.5 (1/2=0.5 i.e. 50%)	0.25 (((1/2)/2) = 25%)	0.25 (25%)	1 (100%)

Step 6: Multiplying the percent value with the warranty budget allocated to the function (as determined in step 2) results in the warranty budget allocated to individual components in order to reliably fulfill the function of interest.

Step 7: The budgets apportioned to each component function-wise are now summed up component-wise resulting in the allowable per-component warranty budget.

Step 8: The allowable warranty budget of a component is divided by the expected total costs for rectifying one warranty claim (i.e. replacing the component etc.) filed by a customer. This data is considered as a given. These costs are known in case of a predecessor product or can be estimated in relation to its complexity. The result is the number of financially allowable failures per component (during the same time the warranty budget was defined for, e.g. 1 year).

Step 9: The reliability goal for the component at the end of the warranty-time can be determined by dividing the total number of units still intact (cf. Step 8) by the total number of components in the field (i.e. as planned).

Optional step: The failure rate could be assumed to be constant over the product's lifetime. In case the failure rate cannot be assumed to be constant, the Weibull distribution can serve to describe the (planned) failure behavior, for which additional information is required on its parameters such as the shape or scale parameter.

Step 10: By means of the system reliability structure, the system's goal reliability can be calculated applying Boole-theory formula.

## 5. ILLUSTRATIVE EXAMPLE

All steps of the methods are quantitatively summarized in Table 5.

Suppose a product consisting of seven components ( $i=1,2,3\dots7$ ) provides three functions which have been identified by the manufacturer in accordance with the customer (step 1).

Step 2: The functions are ranked by means of a pair-wise comparison (cf. Table 4), a common method for prioritizing alternatives [11]. Reading from left to right, the values have the following meaning: 1= less important than; 2=as important as; 3= more important than.

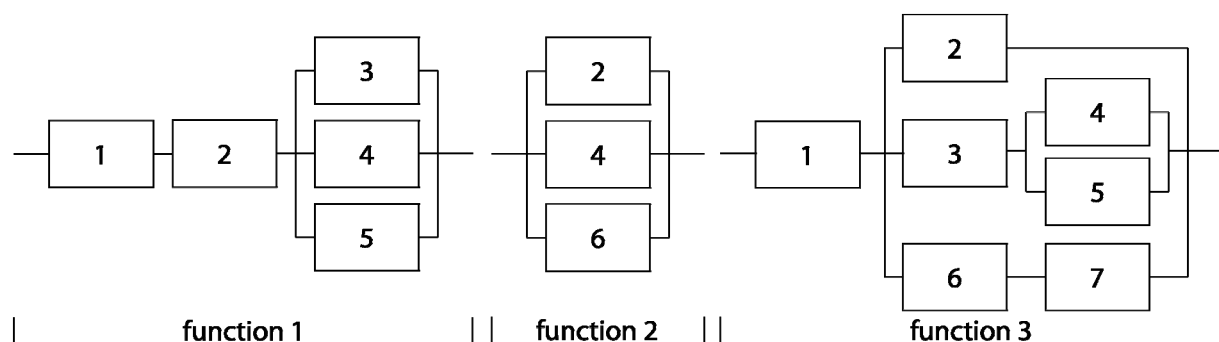
**Table 4: Ranking of Functions by Pairwise Comparison**

	Function 1	Function 2	Function 3	Sum	Rank	Importance
Function 1	-	3	3	6	1.	50%
Function 2	1	-	3	4	2.	33%
Function 3	1	1	-	2	3.	17%

Step 3: Suppose management has decided to allocate the warranty budget over the warranty time of 2 years to be €100,000. The allocated warranty budgets per function result at €50,000 for function 1, €33,000 for function 2 and €17,000 for function 3.

Step 4: Find the reliability structure per function. In this example, the structures are found to be as illustrated in Figure 3. Such a reliability structure can have scalable detail which makes the method applicable at early or later stages of development. Please note that not all components contribute to all functions. The structures can be arbitrarily complex.

**Figure 3: Reliability Structure per Function of the Exemplary Product**



Step 5: The individual component's contribution to the function is analyzed similar to the example in chapter 4.2. Such a correlation often stems from the House of Quality or as part of a value managerial analysis [10]. Please note that in function 3, the same influence factor needs to be allocated to components 6 and 7 since they are in series, i.e. they are equally important. Components 4 and 5 combined represent the same importance as component 3. As they are redundant to each other, their individual importance is half as great as that of component 3 (cf. Example of chapter 4.2.). Please find all calculated contributions in Table 5.

Step 6: By multiplying the per-cent value with the allowable warranty budget of each function, each component's share is derived. Component 1 was found to contribute 33% toward the fulfillment of function 1. Therefore,  $0.33 \cdot €50,000 = €16,667$  are allocated to that component for the matter of function 1.

Step 7: The per-component-and-function budgets are added up component-wise resulting in the budget total per component which can be interpreted as the maximum allowable warranty budget to be spent on the given component. Component 2 for instance contributes to all of the fictional functions in this example. The allowable warranty budget for component 2 sums up to  $€16,667 + €11,000 + €2,125 = €29,792$ .



Step 8: In order to determine the maximum number of allowable failures, information is needed on the per-component costs for rectifying a warranty claim, e.g. the replacement costs for each component. In case of an existing predecessor product, this amount would be known from e.g. field data. If such a predecessor product does not exist (as is the case of a new product development), the costs need to be estimated. The replacement costs for component 1 are in this example assumed to be €100, for component 2 to be €500 etc.

The maximum allowable number of failures per component is then calculated by dividing the per-component budget total by the component's replacement costs. For component 1, the number of allowable failures is thus €23,042/ €100 = 230.4, i.e. 230.

Step 9: Reliability can be empirically expressed as the number of items still intact divided by the total number of items [3,9]. The planned yearly output quantity is 5,000 units, i.e. 10,000 units per two years. The minimum reliability for component 1 at the end of the design period (2 years) is  $R_{1,min}(t=2\text{years}) = (10,000 - 230)/10,000 = 0.9770 = 97.70\%$ . Component 1's minimum reliability after 2 years has thus been derived to be  $R_{1,min} = 97.70\% = R_1(t_w)$  representing its reliability goal.

Optional step: If the applicant of the method supposes a constant failure rate over the warranty time  $t_w$  (as is the case for exponential failure distributions, i.e. Weibull shape parameter  $b=1$ ), it can be easily calculated. For constant failure rates, the reliability at time  $t_w$  can be calculated as follows [3,9]:

$$\lambda = \frac{-\ln(R(t_w))}{t_w}$$

The resulting failure rate for component 1 over two years is  $\lambda_1 = -(\ln(0.9770))/2 = 11.634 \cdot 10^{-3}$  (1/year), representing the maximum allowable constant failure rate.

If the applicant of the model is dedicated to determining a Weibull failure distributions with a shape parameter  $b \neq 1$ , two alternatives are briefly discussed below, which all use  $R_{i,min}(t_w)$  as a given input.

- a. If the lifetime of the component  $T$  is required to have a certain (minimum) value (or can be estimated e.g. based on predecessor versions of the component or has been defined as a strategic goal), the component-specific (maximum) Weibull shape parameter  $b$  can be calculated by [3]

$$b = \frac{\ln(-\ln(R_{i,min}))}{\ln\left(\frac{t_w}{T}\right)},$$

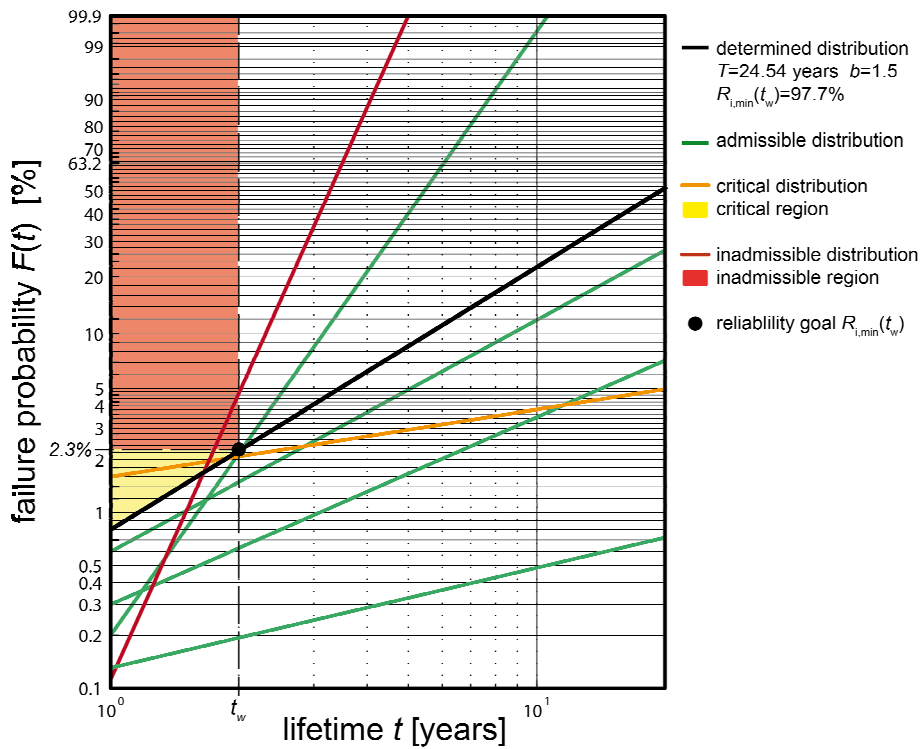
where  $R_{i,min}$  is the reliability goal for the individual component at the end of the warranty time  $t_w$ .

- b. If on the other hand the shape parameter  $b$  of the component is known, i.e. the Weibayes method is applicable [12], the component's lifetime  $T$  can be found by [3]

$$T = (-\ln(R_{i,min}))^{-\frac{1}{b}} \cdot t_w .$$

In case the failure distribution of the component was to be described best by a shape parameter  $b = 1.5$ , the resulting lifetime  $T$  is obtained to  $T=24.54$  years. The situation is illustrated in the Weibull plot of Figure 4. If a combination of  $b$ - and  $T$ - values for a distribution crosses the red area, it is to be regarded as inadmissible as it will lead to an inferior reliability. Distributions crossing the critical region have in common, that an elevated amount of failures occur at a very early stage before  $t_w$ , which

**Figure 4: Weibull Plot of Different Failure Distributions**



is financially unfavorable from the manufacturer's point-of-view. Furthermore, it may lead to particularly disappointed customers.

Step 10: The system's reliability goal  $R_{System}$  can now be calculated applying Boole-theory [3]. In order to do so, the system's reliability structure needs to be known, which in the assumed case equals the serial connection of all functions (cf. Figure 3). The reliability structure expressions per function are as shown in Table 5 where their values are also indicated:

**Table 5: Reliability Formula and Values for the Illustrative Example**

	Reliability formula	Reliability
Reliability for function 1, $R_I$ :	$=R_1 * R_2 * (1 - (1 - R_3) (1 - R_4) (1 - R_5))$	97.1236%
Reliability for function 2, $R_{II}$ :	$=1 - (1 - R_2) (1 - R_4) (1 - R_6)$	99.9999%
Reliability for function 3, $R_{III}$ :	$=R_1 * [1 - (1 - R_2) (1 - (R_3 * (1 - (1 - R_4) (1 - R_5)))) (1 - (1 - R_6 R_7))]$	97.6986%
Reliability for the system $R_{System}$ :	$=\{ R_1 * R_2 * (1 - (1 - R_3) (1 - R_4) (1 - R_5)) \}$ $* \{ 1 - (1 - R_2) (1 - R_4) * (1 - R_6) \}$ $* \{ R_1 * [1 - (1 - R_2) (1 - (R_3 * (1 - (1 - R_4) (1 - R_5)))) (1 - (1 - R_6 R_7))] \}$	94.8883%

In case the costs for achieving the individual component's target reliability level as derived in the method presented here are to be estimated, the method by Mettas [8] could be used for instance.

**Table 6: Stepwise Determination of the Reliability Goal**

		Component							Total
		1	2	3	4	5	6	7	
Function 1 (€50,000)	Influence (absolute value)	1	1	1/3	1/3	1/3	0	0	3
	Influence (per-cent value)	1/3 (33%)	1/3 (33%)	1/9 (11%)	1/9 (11%)	1/9 (11%)	0	0	1 (100%)
	Budget share	€16,667	€16,667	€5,555	€5,555	€5,555	0	0	€50,000
Function 2 (€33,000)	Influence (absolute value)	0	0.33	0	0.33	0	0.33	0	1
	Influence (per-cent value)	0	0.33 (33%)	0	0.33 (33%)	0	0.33 (33%)	0	1 (100%)
	Budget share	0	€11,000	0	€11,000	0	€11,000	0	€33,000
Function 3 (€17,000)	Influence (absolute value)	1	1/3	1/3	1/6	1/6	1/3	1/3	8/3
	Influence (per-cent value)	3/8 (37.5%)	1/8 (12.5%)	1/8 (12.5%)	1/16 (6.25%)	1/16 (6.25%)	1/8 (12.5%)	1/8 (12.5%)	1 (100%)
	Budget share	€6,375	€2,125	€2,125	€1,062.5	€1,062.5	€2,125	€2,125	€17,000
Budget total		€23,042	€29,792	€7,680	€17,617.5	€6,617.5	€13,125	€2,125	€100,000
Repl. costs		€100	€500	€300	€1000	€750	€800	€100	€3,750
Max. failures		230	59	25	17	8	16	21	n/a
$R_{i,\min}(t_w)$		<b>97.70%</b>	<b>99.41%</b>	<b>99.75%</b>	<b>99.83%</b>	<b>99.92%</b>	<b>99.84%</b>	<b>99.79%</b>	n/a
Failure rate (over $t_w$ )		11.634 $\cdot 10^{-3}$	2.959 $\cdot 10^{-3}$	1.252 $\cdot 10^{-3}$	0.851 $\cdot 10^{-3}$	0.400 $\cdot 10^{-3}$	0.801 $\cdot 10^{-3}$	1.051 $\cdot 10^{-3}$	n/a

## 6. CONCLUSION

The method presented here as summarized by means of the flow chart in Figure 1 is able to derive subsystem target reliability levels and thereafter the system's reliability target based on value to the customer and warranty budgets. The procedure starts off by putting the customer requirements toward the functions of the product in the focal point since the product to be developed is persistently perceived as a means of fulfilling the functionality the customer wants. In order to assure the maximum customer satisfaction, statistically inevitable failures during the granted warranty time are compensated for by the manufacturer. Allocating allowable warranty budgets to each subsystem based on its importance toward fulfilling the system's functions ultimately results in the allowable number of failures per warranty time, whereupon reliability relevant parameters can be derived. This results in a reliability allocation as much in line with the voice of the customer as possible.

Contrasting with existing methods, the one presented here is able to combine the determination of a system reliability target with breaking it down to subsystem reliability targets. Also, the method does not depend as heavily as e.g. the method ARINC, AGREE, the Feasibility of Objectives or the method by Karmioli, Bracha and Mettas on empirically defined factors. This enhances the applicability of the method significantly. Furthermore, the method can be applied in early development stages of either a new product development or of design changes as long as the system structure per function can be

determined. How encompassing a function is regarded is scalable. The method is also applicable to arbitrarily complex systems.

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