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*Research article*

# Teaching of system reliability based on challenging practical works using a spreadsheet software

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**Abstract:** Systems reliability is usually an integral part of the curriculum for industrial engineering students. Very often, teachers limit themselves to a theoretical approach or simple calculations. Indeed, dedicated software is either expensive or complex for the intended use. Through this article, the objective is to teach students to create, by themselves, simple but adapted calculation tools from simple models given in a spreadsheet given in parallel with this article, allowing them to apply the theoretical knowledge acquired in the field of reliability. They will be able to easily understand the calculation of reliability thanks to the method of the functional diagram of reliability. Autonomously, they will be able to model most of the systems they might encounter in their engineering career. The developed tool will allow students to calculate the reliability of series systems, parallel systems, mixed systems, $k$-out-of-$n$ systems, bridge systems and other complex models using the method of decomposition or the event space method. In the end, not only will readers be able to carry out the practical work proposed in this article, but the autonomy and skills they will have developed will allow them to model any industrial system or device in the way they deem appropriate.

**Keywords:** remote teaching and learning; practical work; industrial engineering; reliability
**Mathematics Subject Classification:** 97U50, 97K80

## 1. Introduction

The first complete practical work teaching material has recently been published in 2022 by Sauvey [1]. He offers, alongside his paper, a spreadsheet file with holes, intended for students, which mathematically models electrical circuits with a classic spreadsheet software. Such digital practical works are timeliness, particularly on these days where pedagogical matter is supposed to be given by Google or AI, because the plethora of links is losing the workers who try to explore this jungle to study a subject. This work is particular and different from all the existing up-to-date works because it gives the opportunity to the reader to progress thanks to pedagogically designed exercises of increasing difficulty on a hole work, in which not everything is pre-made. The working progression proposed in this paper proves that not only the work has been designed in a student motivating and pedagogical way, but also with the intention to let the students work on their tasks asynchronously and autonomously, because clear instructions on how to make the work and self correct it are given in the paper. The similarities with some previously published studies deals with the willingness to share some material [2]. The originality is that we give the base of a modeling work, with the keys to succeed in completing it. Then, the reader will be able to continue, by themselves, to further develop the work, with an easily obtainable spreadsheet software. This paper is, as far as we know, the only one that proposes turnkey remote teaching practical works both to students and teachers.

As asserted at the end of the first paper: "possibilities are infinite". This article is part of this line, and offers students and their teachers turnkey practical work of increasing difficulty. This article deals with industrial engineering, with the modeling of the calculation of the reliability of any industrial system according to that of each of its components.

### *1.1. Literature review*

Interest for online works is exponentially growing, not only due to the COVID-19 crisis arising, but also due to the war between Russia and Ukraine, and more generally to all the disasters that threaten our interconnected world. As usual, with new issues come new opportunities, and proposing new practical work in industrial engineering is a great opportunity to raise awareness among the public about industrial systems reliability calculation issues.

What was impossible before is now becoming the "normal" situation. Even if, as pointed out in a review paper proposed by Stewart, after the first emergency remote teaching (ERT) shock, differing stakeholder priorities arise and mental health issues appear [3], financing organizations are now asking for half of the teaching hours being done remotely. Changes in teaching modalities, course workload and evaluation and necessary adaptation to a completely different paradigm appear secondarily. In another review paper, Mazlan et al. globally conclude that ERT could be OK for tertiary institutions [4]. They also conclude that the break in pedagogical continuity is something difficult to accept, both for students and for teachers. However, as everyone has seen, sometimes we are forced to collectively face unexpected situations just to survive.

We propose a solution to quickly adapt to a remote teaching situation. It gives a turnkey project for industrial engineering practical work, with all the necessary matter for an undergraduate student to develop oneself an industrial system reliability simulator, with a mere spreadsheet software (Excel for instance). The need to find ways to motivate and engage students and address the loss of hands-on learning opportunities was reported by many teachers in a 2020 study by Hamilton et al. [5].

As could be done in face-to-face teaching, the way to program the major formulas in a spreadsheet is explained in this paper. In addition, some expected results are presented in its figures. By reading this paper, students will not only be able to recreate their own software environment, with their course equations written in spreadsheet form, but they will also be able to improve this file with whatever modifications they deem appropriate. Thus, through their autonomous work, students will also develop their ability to adapt, which is very useful for encouraging creativity, two qualities highly sought after in the industrial world.

We quickly notice that the scientific literature on this subject is rare. This is due to old habits, and to the technological, educational and social challenges that suddenly arise [6]. Hamilton et al. report that student engagement and practice are crucial in a teaching experience, and opportunities for hands-on learning should be addressed [5]. This is why we give the first version of a tutorial on modeling and calculating the reliability of an industrial system.

A literature review was carried out in [1], studying 44 papers, dealing with distance learning and practical work. The reader will validly rely on this recent review on these subjects. Existing work on the transition from face-to-face to distance learning, practical work in the educational process, experiments in distance laboratories, are analyzed as well as the gains that can be expected for students. Then, the pros and cons of distance education are listed from the author's personal perspective. The major advantages are: The effective use of teaching aid computer programs, security issues are directly addressed, the possibility of working asynchronously, the study and analysis of curves can be deepened where they can be switched by default of time in face-to-face learning, and more generally to the deepening of subjects related to the subject of practical work. As expected, the drawbacks identified for distance learning relate to the impossibility for the student to practice "with the hands" and the absence of feedback. A recent paper by Zajdel et al. confirms the presence of a correlation between the technical conditions of classes and the specific forms and levels of education [7]. Respondents indicate that distance learning depends mainly on the quality of technical parameters, including a good or very good internet connection. The major reported benefits of online learning are the ability to work from home, easily share course materials and use of additional teaching aids. Health problems and long periods spent in front of the computer were highlighted as the biggest drawbacks of this teaching method. Interestingly, the results also showed that as the age of teachers increases, acceptance and trust in distance learning activities increases while students' fear of using this form of learning decreases.

With the rapid growth of economics, science and technology, with less and less attention paid to the modernization and development of work, an empirical evaluation of the practical aspects of interdisciplinary agriculture in agricultural colleges is done in [8]. Problems with current practical teaching methods from the perspective of teaching materials, practical teaching, teaching platforms and teachers are also approached and recommendations for improvement are given. Teaching has also been instantiated as an optimization method, and Zhong et al. have combined the marine predator algorithm with a teaching-learning based optimization algorithm, and propose a hybrid algorithm called the teaching-learning based Marine predator algorithm (TLMPA) [9]. As far as industrial engineering is concerned, models are published, even without the primary purpose of teaching. A decentralized supply chain network with uncertain cost is proposed in [10], to obtain the optimal business decisions under an uncertain cost situation. Health systems are also the place where modeling is useful, mainly for the spread of epidemics. The volatility of the exchange rate under the jump process and the analysis of the applications were modeled by Liu et al. [11]. Their analysis reveals that exchange rate fluctuations exhibit several obvious characteristics, such as spikes, fat tails, fluctuation aggregations and asymmetry. Their double exponential jump model can fully handle and capture the fluctuating characteristics of returns, and is particularly useful in predicting exchange rate fluctuations, providing a benchmark for effective management of exchange rate risk in China, and further improving the financial risk management mechanism. The dynamic behavior of an epidemic system characterized by a half-saturated transmission rate and significant evidence of crossover behavior has been studied by Al-Qureshi et al. [12]. Ndenda et al. developed and analyzed a fractional order model for the transmission dynamics of Lassa fever, which involves transmissions from rodents to humans, from person to person, as well as the environment/surfaces infested with Lassa virus [13].

In addition, in sub-Saharan Africa, anemia and malaria are the main causes of morbidity and mortality in children under five. These two diseases have been studied for the country of Guinea, where they have particularly devastating effects. They were jointly estimated with the spatial linear correlation between them, and the differences in contextual, socioeconomic and demographic factors affecting morbidity among children under five years in Guinea have also been studied [14].

Practice is very important in a teaching process, regardless of the age of the learner [15]. The practice of reliability has been challenged [16], and still is today [17]. It is indeed costly, in terms of equipment, maintenance staff, partial occupation of surfaces, small groups, *etc.* Its effectiveness has also been questioned [18]. Examples of practical distance learning tests can be found for geography [19], medical sciences [20], dynamics of linear electrical systems [21], electronics converter design fly-back power [22], physics and engineering sciences [23], elastic coupling drive system [24], time-varying quasi-static fields [25], power electronics [26] and electrical circuit modeling [1].

The justification for using Excel (or a "*Excel-like*" spreadsheet) seems appropriate to us since this work is intended for students. The advantages of using Excel for students are: The feasibility of the work, the accessibility and availability of such software, the possibility of progressing by themselves, at their own pace, simplicity and direct feedback on the result of their work. The major drawbacks are: The difficulty of monitoring large projects, the almost obvious need to create a file per need, the limits of interfacing, the superiority of professional tools more suitable for industrial purposes. The major objectives of this paper directly qualify these softwares for pedagogical and accessibility reasons.

### *1.2. Contributions of this paper*

The major contributions of this paper are presented below, as they were presented in [1], because they are exactly the same, but on a different subject. Of course, as long as the practical work presented in this article is supposed to be carried out remotely, one can expect the benefits seen on the remote work literature. Anyway, an added benefit of this item is the actual start of the targeted streak.

**For the teachers:**

(i) This paper gives a set of examples that could be used in teaching and provided to students as resource or as a self-paced tutorial, thus enhancing their autonomy and self-willingness to progress.

(ii) Additionally, it gives "concrete" rather than "abstract" means of representing the conceptual reliability models.

(iii) It also gives the example of a way to automating the calculations in a user-friendly way in readily-available software.

**For the students:**

(i) This paper is a **"do it yourself"** proposal made to the students. Indeed, this paper can be loaded as the subject of remote practical works, or also possibly a project supervised by a tutor. This proposal is also an originality of this paper, and the promise of autonomy contained in this project further motivates the students, who wish to get involved in such projects that become personal to them. They generally appreciate this kind of proposal and take it to prove what they are capable of doing.

(ii) In addition, the **"keep it yourself"** pledge is given to students. The model given in the database is in fact completely loadable by anyone, but its complete possibilities of understanding, control and modification are directly related to the skills that will be developed by each student, not only during the activity of practical work but even afterwards, if the student decides to keep, maintain and improve this file. The relevance of giving the file next to the article avoids the possible problems of availability which can occur on the sites of the private universities [2].

### *1.3. Paper outline*

This document is organized as follows. Section 2 is devoted to explaining the 2 simplest examples usually taken to explain what system reliability is. For this purpose, serial and parallel systems are modeled and simulated. Then, Section 3 goes up a notch with the presentation of the three major methods used to assess the reliability of industrial systems. The methods of reduction, decomposition and event space are successively presented and illustrated. Then, the implementation of all these methods in a spreadsheet is respectively presented in Section 4, with the tricks to succeed in these tasks. The conclusion section summarizes the advantages and contributions of this article for students and teachers, as well as some limitations, and gives some perspectives to this work.

## 2. Understanding systems reliability

Reliability is a decisive factor in ensuring the efficient operation of production systems in the industrial sector. Reliability is used in a variety of fields, including power grids, medical devices and telecommunications networks. Understanding and measuring the reliability of systems is, therefore, of fundamental importance. The concept of reliability represents the ability of these systems to perform their functions without failure, under specific conditions and within defined time frames. However, reliability is not limited to these aspects. It is also about consistently delivering the desired performance, adhering to safety standards and meeting user needs and expectations.

With our complex and interconnected systems, the consequences of failure can be significant. Without being exhaustive, they can take different forms, such as a drop in productivity resulting in financial losses, or security problems that can damage the reputation of the brand. Assessing and quantifying system reliability is therefore essential to identify potential weaknesses, improve design robustness and implement appropriate maintenance strategies. By evaluating this probability of failure, it is possible to assess the ability of the system to perform the intended functions reliably and to make appropriate decisions to optimize the operation and maintenance of these systems.

In the field of system reliability analysis, the reliability block diagram (RBD) method has established itself as a simple and effective tool. RBDs provide a graphical representation of the structure of the system, illustrating the relationships between components. This representation allows a quick understanding of the architecture of the system. Critical components are easily detected and their impact on system reliability can be determined efficiently. The RBD method is very flexible, allowing it to represent different system configurations, such as series and parallel components, $k$-out-of-$n$ systems and even complex systems. The ease of use of RBDs also allows engineers to design reliable systems from the earliest stages of development. It also offers the advantage of being able to be integrated with other reliability analysis techniques (fault tree to evaluate the root causes of failure, Monte Carlo simulations to take into account uncertainties and variations in performance evaluation). For the purposes of this article, we will focus only on the study of RBDs.

### *2.1. Assumptions*

From a mathematical point of view, an RBD method is an acyclic directed graph, that is, it has one input and one output and does not contain any loop or feedback. It is based on the following fundamental assumptions:

- The system has only two states (for example: working/failing).
- Blocks have only two states (for example: working/failing).
- The RBD represents the logic function linking the system's operating state to the operating states of its blocks.
- Blocks are independent of each other.
- As many repairers as blocks (independence of maintenance strategies).

### *2.2. Notations*

- $i$: index for each component $C_i$ ($i = 1, \cdots, n$).
- $x_i$: state of the component $C_i$ ($x_i = 1$ if component is working, 0 else).
- $\varphi(x)$: system structure function ($\varphi(x) = 1$ if system is working, 0 else).
- $X_i(t)$: state of the component $C_i$ at time $t$.
- $r_i(t)$: reliability of the component $C_i$ ($r_i(t) = \mathbb{P}(X_i(u) = 1, \forall u \in [0, t])$).
- $R_{\text{System}}(t)$: system reliability based on individual component reliability and system configuration.

### *2.3. Elementary systems*

#### 2.3.1. Series system

A system is considered a series system if the correct operation of the system requires the correct operation of all its components simultaneously. That is to say, only one of the components is down, the system is down.

As can be seen in Figure 1, the series system is illustrated graphically.

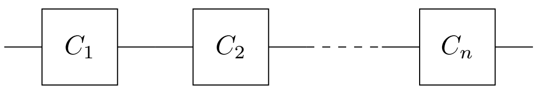



**Figure 1.** Graphical representation of a series system.

The structure function of a series system is given by the minimum or the product of the states of the system components:

$$\varphi(x) = \min(x_1, x_2, \cdots, x_n). \tag{2.1}$$

The probability of the system working is the probability of $\varphi(x) = 1$,

$$\mathbb{P}(\varphi(x) = 1) = \mathbb{P}(x_1 = 1, x_2 = 1, \cdots, x_n = 1). \tag{2.2}$$

Given that the components are assumed to be independent, this probability is transferred to the probability product of all components:

$$\mathbb{P}(\varphi(x) = 1) = \mathbb{P}(x_1 = 1) \cdot \mathbb{P}(x_2 = 1) \cdots \mathbb{P}(x_n = 1). \tag{2.3}$$

Based on time, we get the reliability:

$$\begin{aligned} R_{\text{System}}(t) &= \mathbb{P}(X_1(t)=1)\cdot\mathbb{P}(X_2(t)=1)\cdots\mathbb{P}(X_n(t)=1) \\ &= r_1(t)\cdot r_2(t)\cdots r_n(t) \\ &= \prod_{i=1}^{n} r_i(t). \end{aligned} \tag{2.4}$$

2.3.2. Parallel system

Unlike a series system, a parallel system is functional if at least one of its components is non-faulty. In a parallel system, all components are always working (active redundancy). A graphical description of a parallel system is shown in Figure 2.

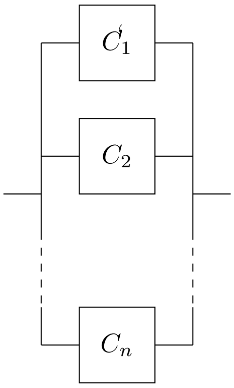



**Figure 2.** Graphical representation of a parallel system.

The failure of the system occurs if and only if all components fail simultaneously. In this case, the structure function is given by:

$$\varphi(x) = \max(x_1, x_2, \cdots, x_n). \tag{2.5}$$

For reliability, the possible cases being multiple, we are first interested in the opposite case: the probability of failure of the system. As the failure of the system can only occur on failure of all the elements, we have:

$$\mathbb{P}(\varphi(x)=0) = \mathbb{P}(x_1=0, x_2=0, \cdots, x_n=0). \tag{2.6}$$

Since the components are assumed to be independent, this probability is transferred to the product of the failure probability of all components.

$$\begin{aligned} \mathbb{P}(\varphi(x)=0) &= \mathbb{P}(x_1=0)\cdot\mathbb{P}(x_2=0)\cdots\mathbb{P}(x_n=0) \\ &= \prod_{i=1}^{n}\mathbb{P}(x_i=0) \\ &= 1-\prod_{i=1}^{n}(1-\mathbb{P}(x_1=1)). \end{aligned} \tag{2.7}$$

Based on time, reliability becomes:

$$R_{\text{System}}(t) = 1 - \prod_{i=1}^{n} \left(1 - \mathbb{P}\left(X_i(t) = 1\right)\right)$$
$$= 1 - \prod_{i=1}^{n} \left(1 - r_i(t)\right). \tag{2.8}$$

2.3.3. *k*-out-of-*n* system

A $k$-out-of-$n$ system is composed of $n$ components, and its graphical representation is given in Figure 3. The system is in good condition if at least $k$ ($1 \leq k \leq n$) components among $n$ are in good condition. System failure falls when $n - k + 1$ or more components fail simultaneously.

A $k$-out-of-$n$ system can be thought of as a series of $n$ independent tests, each with two possible outcomes (working or failure), with a constant probability of success or failure for each test. For example, if we have a system with 10 elements and 8 of them must work for the system to be reliable, we can consider each element as a test with a probability of 0.8 of success (reliability) or 0.2 of failure.

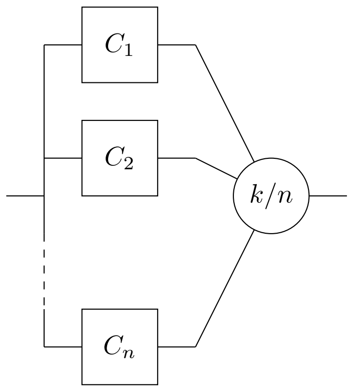



**Figure 3.** Graphical representation of a $k$-out-of-$n$ system.

The structure function of a $k$-out-of-$n$ system is given by:

$$\varphi(x) = \begin{cases} x = 1, & \text{if } \sum_{x=1}^{n} x_i \geq k, \\ x = 0, & \text{otherwise.} \end{cases} \tag{2.9}$$

Assuming that the $n$ components have the same reliability function $r(t)$, from the previous equations, the reliability of the complete system is expressed as follows:

$$R_{\text{System}}(t) = \sum_{i=k}^{n} C_n^i r(t)^i (1 - r(t))^{(n-i)}. \tag{2.10}$$

When components have different reliability values, it is necessary to determine all combinations and it is no longer possible to establish a general formula. The reader can refer to the end of Section 3.1 to understand the methodology implemented.

## 3. Methods for assessing the reliability of systems

To improve the readability of the equations and the understanding of the different models, we relax the notion of time in this section. Therefore, we will assume that the reliabilities of the components, and therefore of the system, are independent of time.

### *3.1. Reduction method*

For systems composed of several easily identifiable subsystems, the reduction method can be applied. It consists of identifying, on a recurring basis, the subsystems/components and calculating the corresponding reliabilities. By applying the reliability calculation rules described in sections x, y and z, it is possible to obtain the reliability of the system.

Consider the *RBD* , proposed by [27], represented by Figure 4. The reliabilities of the 5-component system are defined by the respective values {0.70, 0.73, 0.76, 0.79, 0.82} for the components 1 to 5.

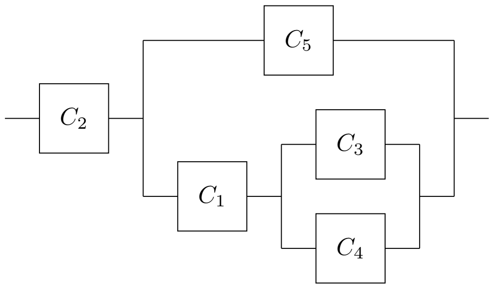



**Figure 4.** RBD used to illustrate the reduction method.

This system can be reduced into several elementary subsystems, as illustrated in Figure 5, such as:

- Components 3 and 4 form a parallel system with two elements, denoted “SubSystem A”.
- The set composed of component 1 and “SubSystem A” represents a serial system, named “SubSystem B”.
- The parallel system made of component 5 and “SubSystem B” can be replaced by an equivalent “SubSystem C” component.

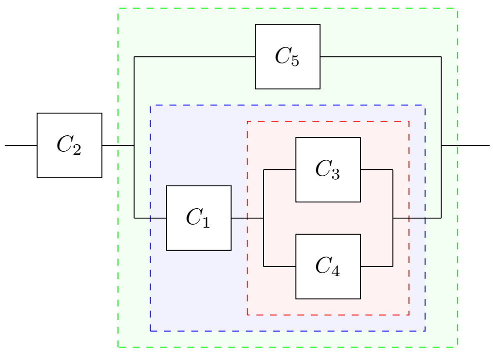



**Figure 5.** RBD with subsystems used to illustrate the reduction method.

Finally, the reliability of this system can be expressed by :

$$
\begin{aligned}
R_{\text{System}} &= R_2 \times \underbrace{\left[ 1 - (1 - R_5)\,(1 - \overbrace{R_1 \times \underbrace{[1 - (1 - R_3)\,(1 - R_4)]}_{R_{\text{SubSystem A}}}}^{R_{\text{SubSystem B}}}) \right]}_{R_{\text{SubSystem C}}} \\
&= 0.73 \times [1 - (1 - 0.82)(1 - 0.7 \times [1 - (1 - 0.76)(1 - 0.79)])] \\
&\approx 0.68594421. \qquad (3.1)
\end{aligned}
$$

### *3.2. Decomposition method*

Often, the systems encountered in reality cannot be reduced into simple subsystems. For more complex systems, alternative methods exist, such as the decomposition method based on Bayes' theorem. This method consists in choosing a keystone component (KC) and calculating the reliability of the system in the two following situations:

- The KC failed ($R_{\text{KC}} = 0$).
- The KC succeeded ($R_{\text{KC}} = 1$).

Afterwards, the two probabilities are added to obtain the reliability of the system, given that at any time the system works or fails.

$$
\begin{aligned}
R_{\text{System}} &= \mathbb{P}\,(\text{System} \cap \text{KC}) + \mathbb{P}\left(\text{System} \cap \overline{\text{KC}}\right) \\
&= \mathbb{P}\,(\text{System}|\text{KC})\,\mathbb{P}\,(KC) + \mathbb{P}\left(\text{System}|\overline{\text{KC}}\right)\mathbb{P}\left(\overline{\text{KC}}\right). \qquad (3.2)
\end{aligned}
$$

According to the complexity of the systems, it may be necessary to take into consideration several key elements.

To illustrate the decomposition method, the example usually used concerns the bridge system (see Figure 6).

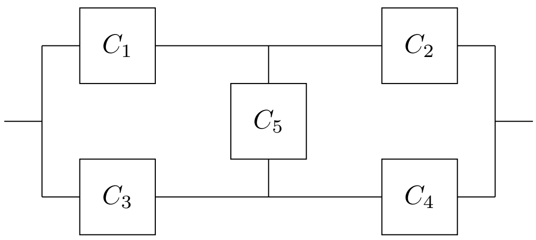



**Figure 6.** Bridge system.

Let us consider the respective values {0.70, 0.73, 0.76, 0.79, 0.82} for the reliability of components 1 to 5, and the component 5 as the KC. As mentioned in [28], "*the KC is assumed to be 100% reliable and is replaced with a line in system structure. Then, the same component is supposed to have failed and is removed from the system*".

Thus, when the KC never fails, the bridge system becomes a series-parallel system (see Figure 7).

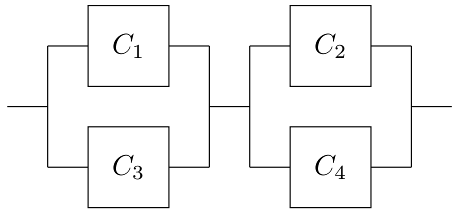


**Figure 7.** Bridge system becomes a series-parallel system when KC never fails.

Based on the Eqs (2.4) and (2.8), the reliability is given by:

$$\begin{aligned}\mathbb{P}\left(\text{System}|\text{KC}\right)\mathbb{P}\left(\text{KC}\right) &= \left[\left(1-(1-R_1)(1-R_3)\right)\left(1-(1-R_2)(1-R_4)\right)\right]\cdot R_{\text{KC}}\\ &= \underbrace{\left[\left(1-(1-0.70)(1-0.76)\right)\left(1-(1-0.73)(1-0.79)\right)\right]}_{0.8753824}\cdot 0.82\\ &\approx 0,71781357. \end{aligned} \tag{3.3}$$

Otherwise, it becomes a parallel-series system when the KC fails (see Figure 8).

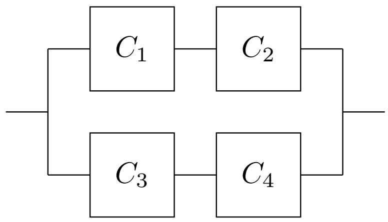


**Figure 8.** Bridge system becomes a parallel-series system when KC fails.

Based on the Eqs (2.4) and (2.8), the reliability is given by:

$$\begin{aligned}\mathbb{P}\left(\text{System}|\overline{\text{KC}}\right)\mathbb{P}\left(\overline{\text{KC}}\right) &= \left[1-(1-R_1R_2)(1-R_3R_4)\right]\cdot(1-R_{\text{KC}})\\ &\approx 0,14482721. \end{aligned} \tag{3.4}$$

Finally, based on Eq (3.2), the reliability of this bridge system is expressed as follows:

$$\begin{aligned}R_{\text{System}} &= \left[\left(1-(1-R_1)(1-R_3)\right)\left(1-(1-R_2)(1-R_4)\right)\right]\cdot R_{\text{KC}}\\ &\quad + \left[1-(1-R_1R_2)(1-R_3R_4)\right]\cdot(1-R_{\text{KC}})\\ &\approx 0,86264078. \end{aligned} \tag{3.5}$$

*3.3. Event space method*

The event space method consists in determining all mutually exclusive events. The reliability of the system is simply the probability of the union of all the mutually exclusive events that result in the operation of the system, noted $E_i$. Then, the reliability of the system is given by:

$$R_{\text{System}} = \mathbb{P}\left(E_i\right). \tag{3.6}$$

To illustrate this event space method, the bridge system will still be used (Figure 6). The Table 1 shows all combinations ($2^5$) that lead to success ($S$) or failure ($F$).

**Table 1.** Table of all mutually exclusive events.

| Success ($S$) | Failure ($F$) |
|---|---|
| $C_1\ C_2\ C_3\ C_4\ C_5$ | $C_1\ \overline{C_2}\ C_3\ \overline{C_4}\ C_5$ |
| $C_1\ C_2\ C_3\ C_4\ \overline{C_5}$ | $C_1\ \overline{C_2}\ C_3\ \overline{C_4}\ \overline{C_5}$ |
| $C_1\ C_2\ C_3\ \overline{C_4}\ C_5$ | $C_1\ \overline{C_2}\ \overline{C_3}\ C_4\ \overline{C_5}$ |
| $C_1\ C_2\ C_3\ \overline{C_4}\ \overline{C_5}$ | $C_1\ \overline{C_2}\ \overline{C_3}\ \overline{C_4}\ C_5$ |
| $C_1\ C_2\ \overline{C_3}\ C_4\ C_5$ | $C_1\ \overline{C_2}\ \overline{C_3}\ \overline{C_4}\ \overline{C_5}$ |
| $C_1\ C_2\ \overline{C_3}\ C_4\ \overline{C_5}$ | $\overline{C_1}\ C_2\ C_3\ \overline{C_4}\ \overline{C_5}$ |
| $C_1\ C_2\ \overline{C_3}\ \overline{C_4}\ C_5$ | $\overline{C_1}\ C_2\ \overline{C_3}\ C_4\ C_5$ |
| $C_1\ C_2\ \overline{C_3}\ \overline{C_4}\ \overline{C_5}$ | $\overline{C_1}\ C_2\ \overline{C_3}\ C_4\ \overline{C_5}$ |
| $C_1\ \overline{C_2}\ C_3\ C_4\ C_5$ | $\overline{C_1}\ C_2\ \overline{C_3}\ \overline{C_4}\ C_5$ |
| $C_1\ \overline{C_2}\ C_3\ C_4\ \overline{C_5}$ | $\overline{C_1}\ C_2\ \overline{C_3}\ \overline{C_4}\ \overline{C_5}$ |
| $C_1\ \overline{C_2}\ \overline{C_3}\ C_4\ C_5$ | $\overline{C_1}\ \overline{C_2}\ C_3\ \overline{C_4}\ C_5$ |
| $\overline{C_1}\ C_2\ C_3\ C_4\ C_5$ | $\overline{C_1}\ \overline{C_2}\ C_3\ \overline{C_4}\ \overline{C_5}$ |
| $\overline{C_1}\ C_2\ C_3\ C_4\ \overline{C_5}$ | $\overline{C_1}\ \overline{C_2}\ \overline{C_3}\ C_4\ C_5$ |
| $\overline{C_1}\ C_2\ C_3\ \overline{C_4}\ C_5$ | $\overline{C_1}\ \overline{C_2}\ \overline{C_3}\ C_4\ \overline{C_5}$ |
| $\overline{C_1}\ \overline{C_2}\ C_3\ C_4\ C_5$ | $\overline{C_1}\ \overline{C_2}\ \overline{C_3}\ \overline{C_4}\ C_5$ |
| $\overline{C_1}\ \overline{C_2}\ C_3\ C_4\ \overline{C_5}$ | $\overline{C_1}\ \overline{C_2}\ \overline{C_3}\ \overline{C_4}\ \overline{C_5}$ |

Considering the event $\overline{C_1}\ C_2\ C_3\ \overline{C_4}\ C_5$ (or more precisely $\overline{C_1} \cap C_2 \cap C_3 \cap \overline{C_4} \cap C_5$), the probability of its occurrence is expressed by:

$$\begin{aligned}
\mathbb{P}\left(\overline{C_1}\ C_2\ C_3\ \overline{C_4}\ C_5\right) &= \mathbb{P}\left(\overline{C_1}\right) \times \mathbb{P}(C_2) \times \mathbb{P}(C_3) \times \mathbb{P}\left(\overline{C_4}\right) \times \mathbb{P}(C_5) \\
&= (1 - R_1) \cdot R_2 \cdot R_3 \cdot (1 - R_4) \cdot R_5 \\
&\approx 0,02866097. \qquad (3.7)
\end{aligned}$$

Summing all mutually exclusive events that lead to success, the reliability of the system is evaluated at $R_{\text{System}} \approx 0,86264078$.

### *3.4. Choice of the appropriate method*

These different methods allow to obtain the reliability of a system in the case of non repairable components. However, it is important to know how to select the most appropriate method according to the system studied: Can the system be split into elementary subsystems?

↪ YES: reduction method.

NO: Can one (or more) keystone element(s) be identified?

↪ YES: decomposition method.

NO: Is it possible to test all ($n^2$) combinations (success or fail)?

↪ YES: event space method.

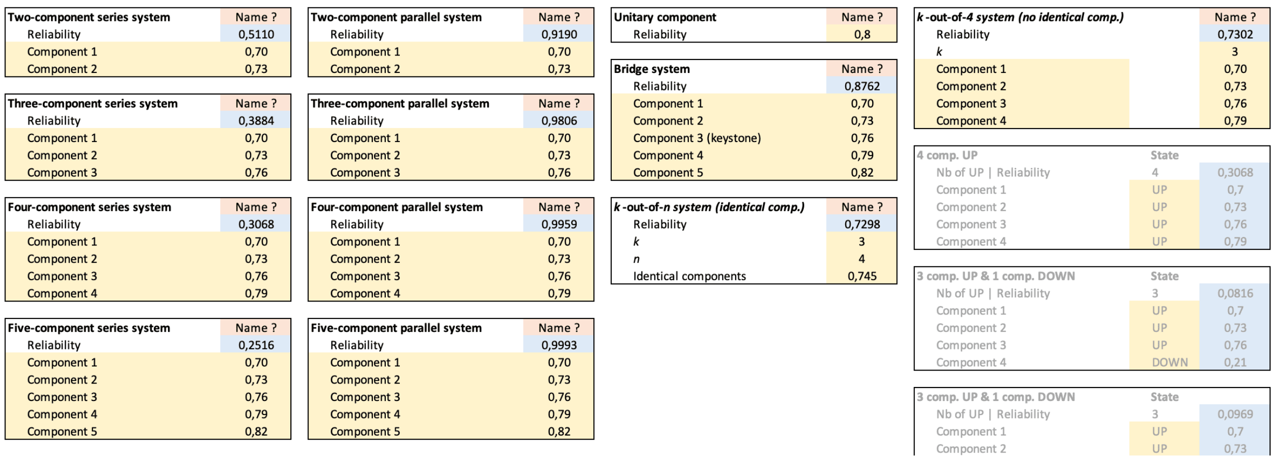
NO: Other complex methods are available such as "Path Tracing and Tie Sets", "Path Breaks and Cut Sets". For more information on these two methods, the reader can refer to [29].

## 4. Implementation of resolution methods in spreadsheet software

The file provided for students can be used without the need for extensive knowledge of spreadsheets and formulas, even if they are explained in this paper.

### 4.1. Implementation of the reduction method

The "Reduction method — Library" sheet contains a set of tables that correspond to the simple structures as shown in Figure 9.



| Two-component series system | Name ? |
|---|---|
| Reliability | 0,5110 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |

| Three-component series system | Name ? |
|---|---|
| Reliability | 0,3884 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |
| Component 3 | 0,76 |

| Four-component series system | Name ? |
|---|---|
| Reliability | 0,3068 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |
| Component 3 | 0,76 |
| Component 4 | 0,79 |

| Five-component series system | Name ? |
|---|---|
| Reliability | 0,2516 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |
| Component 3 | 0,76 |
| Component 4 | 0,79 |
| Component 5 | 0,82 |

| Two-component parallel system | Name ? |
|---|---|
| Reliability | 0,9190 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |

| Three-component parallel system | Name ? |
|---|---|
| Reliability | 0,9806 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |
| Component 3 | 0,76 |

| Four-component parallel system | Name ? |
|---|---|
| Reliability | 0,9959 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |
| Component 3 | 0,76 |
| Component 4 | 0,79 |

| Five-component parallel system | Name ? |
|---|---|
| Reliability | 0,9993 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |
| Component 3 | 0,76 |
| Component 4 | 0,79 |
| Component 5 | 0,82 |

| Unitary component | Name ? |
|---|---|
| Reliability | 0,8 |

| Bridge system | Name ? |
|---|---|
| Reliability | 0,8762 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |
| Component 3 (keystone) | 0,76 |
| Component 4 | 0,79 |
| Component 5 | 0,82 |

| *k*-out-of-*n* system (identical comp.) | Name ? |
|---|---|
| Reliability | 0,7298 |
| *k* | 3 |
| *n* | 4 |
| Identical components | 0,745 |

| *k*-out-of-4 system (no identical comp.) | Name ? |
|---|---|
| Reliability | 0,7302 |
| *k* | 3 |
| Component 1 | 0,70 |
| Component 2 | 0,73 |
| Component 3 | 0,76 |
| Component 4 | 0,79 |

| 4 comp. UP | State | |
|---|---|---|
| Nb of UP \| Reliability | 4 | 0,3068 |
| Component 1 | UP | 0,7 |
| Component 2 | UP | 0,73 |
| Component 3 | UP | 0,76 |
| Component 4 | UP | 0,79 |

| 3 comp. UP & 1 comp. DOWN | State | |
|---|---|---|
| Nb of UP \| Reliability | 3 | 0,0816 |
| Component 1 | UP | 0,7 |
| Component 2 | UP | 0,73 |
| Component 3 | UP | 0,76 |
| Component 4 | DOWN | 0,21 |

| 3 comp. UP & 1 comp. DOWN | State | |
|---|---|---|
| Nb of UP \| Reliability | 3 | 0,0969 |
| Component 1 | UP | 0,7 |
| Component 2 | UP | 0,73 |

**Figure 9.** Library of main systems for reduction and decomposition methods.

The reliability of the series system, expressed by the Eq (2.4), can be expressed simply in the spreadsheet using the PRODUCT function*. The formula is given by:

$$\text{“} = PRODUCT(component1; component2; \cdots)\text{”}.$$

The library has four examples, ranging from two to five components. Based on these examples, students are able to create formulas for series with $n$ components.

Regarding parallel systems, the conversion of the Eq (2.8) in the spreadsheet gives the formula

$$\text{“} = 1 - PRODUCT(1 - component1 : componentn)\text{”}.$$

The sub-expression *component1*:*componentn* corresponds to the adjacent cells, which include the reliability values of the $n$ components.

For a $k$-out-of-$n$ system, reliability is defined as the probability that the number of successes is greater than or equal to $k$. The binomial distribution is used to model such random processes that

*https://support.microsoft.com/en-us/office/product-function-8e6b5b24-90ee-4650-aeec-80982a0512ce involve a finite number of independent trials with two possible outcomes and a constant probability of success (or failure) for each trial. The binomial distribution allows one to calculate the probability of a specific number of successes (or failures) in $n$ trials. This can be calculated using the BINOM.DIST function† in spreadsheet software, which uses the binomial distribution to calculate the cumulative probability of $k$ or fewer successes in $n$ trials. To determine the reliability of the $k$-out-of-$n$ system, the reliabilities for the different scenarios, ranging from $k$ components in use until $n$ components in operation, must be determined. The function BINOM.DIST is used to compute the cumulative distribution function by adding the values obtained since 1. For our case, it will be necessary to compute the complementary event. For this reason, the cumulative function only goes up to $k - 1$. The result is obtained with the formula

$$\text{“} = 1 - BINOM.DIST(k-1, n, reliability, TRUE)\text{”}.$$

When the components differ, it is appropriate to calculate the reliabilities for the different cases from $k$ to $n$. Let's consider a system composed of 4 components ($n = 4$) whereby 3 are necessary for the good functioning of the latter ($k = 3$). The reliabilities of components 1 to 4 are given by {0.70, 0.73, 0.76, 0.79}.

$$\begin{aligned}
R_{\text{System}} &= \mathbb{P}\left(C_1\ C_2\ C_3\ C_4\right) && \Leftarrow && \text{4 components are UP.}\\
&+ \mathbb{P}\left(C_1\ C_2\ C_3\ \overline{C_4}\right) && \Leftarrow && \text{3 components are working ; } C_4 \text{ is failing.}\\
&+ \mathbb{P}\left(C_1\ C_2\ \overline{C_3}\ C_4\right) && \Leftarrow && \text{3 components are working ; } C_3 \text{ is failing.}\\
&+ \mathbb{P}\left(C_1\ \overline{C_2}\ C_3\ C_4\right) && \Leftarrow && \text{3 components are working ; } C_2 \text{ is failing.}\\
&+ \mathbb{P}\left(\overline{C_1}\ C_2\ C_3\ C_4\right) && \Leftarrow && \text{3 components are working ; } C_1 \text{ is failiing.}\\
&= 0.70 \times 0.73 \times 0.76 \times 0.79\\
&\quad + 0.70 \times 0.73 \times 0.76 \times (1 - 0.79)\\
&\quad + 0.70 \times 0.73 \times (1 - 0.76) \times 0.79\\
&\quad + 0.70 \times (1 - 0.73) \times 0.76 \times 0.79\\
&\quad + (1 - 0.70) \times 0.73 \times 0.76 \times 0.79\\
&\approx 0.7302.
\end{aligned} \tag{4.1}$$

Thanks to this library of simple elements (and extensible to the user's needs), the student is able to determine the reliability of systems that meet this reduction method.

Let us consider the example given in Section 3.1 and determine the reliability of this system using the spreadsheet, according to what is presented in Figure 10.

†https://support.microsoft.com/en-us/office/binom-dist-function-c5ae37b6-f39c-4be2-94c2-509a1480770c

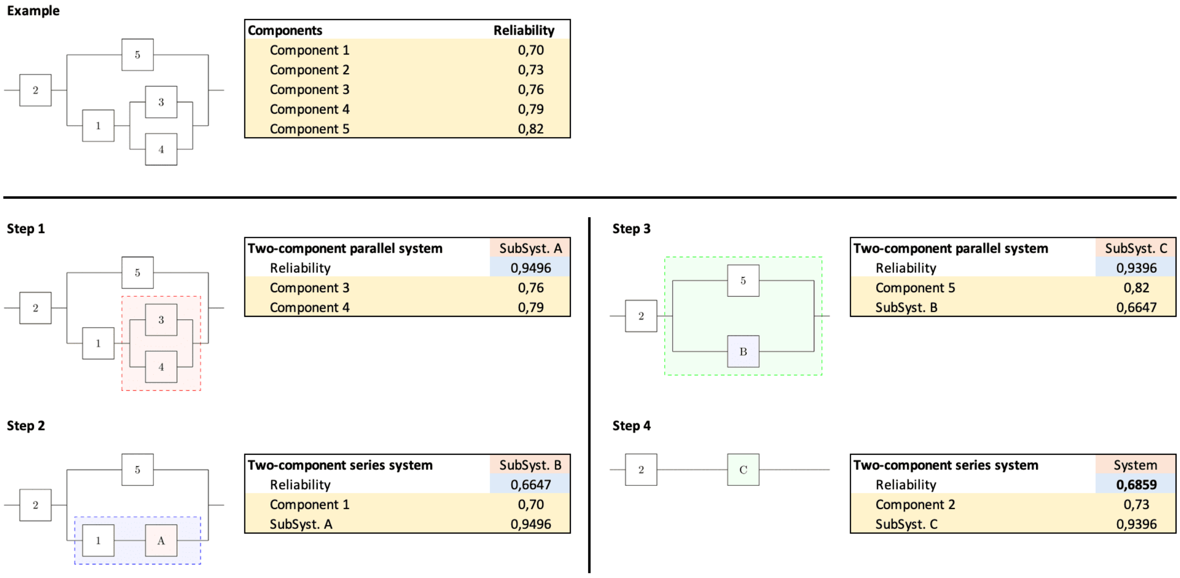



**Figure 10.** Illustrative example of the reduction method.

### 4.2. *Implementation of the decomposition method*

The implementation of the decomposition method on the spreadsheet is very similar to that of the reduction method. It also involves selecting the components or sub-systems that make up the final systems. In this case, several final systems are deduced from the KC(s). The number of final systems is directly linked to the number of key components (KC), based on the $KC^2$ relationship, since each key component must be considered as working or faulty. The system reliability, in the example shown in Figure 11, is determined from the two computed subsystems “SubSyst. UP” and “SubSyst. DW” as well as the status of the KC ($C_5$) as defined by the Eq (3.2).

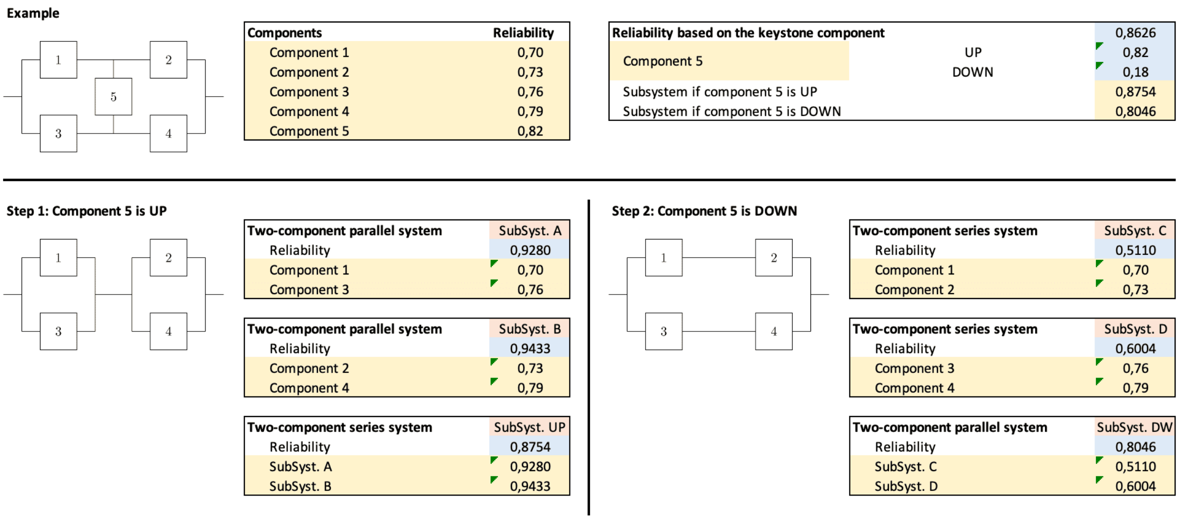



**Figure 11.** Illustrative example of the decomposition method.

*4.3. Implementation of the event space method*

With the "event space" method, all combinations must be listed. Since a component can take two states (working or failing), the number of combinations, for a system with $n$ components, is simply expressed by $2^n$. Thus, for a system with a small number of components, the study of each combination remains possible.

The student must fill the cells to the right of the one entitled "components name" and indicate the corresponding reliability for each component. Based on these indications, all combinations are listed. Currently, the sheet is limited to 10 components, but the student can "stretch" the rows and columns and adapt the formulas. The methodology is rather simple. The first column has an identifier from 1 to the number of possible combinations (here, $2^{10} = 1024$). Using the function named "BASE", this number is converted into binary whose length corresponds to the number of components (thus, for $n = 6$, 1 is expressed as "000001"). From this $n$-character binary number, we extract the values based on the "Component Id" using the formula

$$\text{“} = IFERROR(VALUE(MID(\textit{n-character binary number}, \textit{“Component Id”}, 1)), )\text{”}.$$

- The MID function[‡] returns a specific number of characters from a text string (*n-character binary number*), starting at the position specified (*Component Id*), based on the number of characters specified (1).
- The VALUE function[§] converts the text string that represents a number to a number.
- The IFERROR function[¶] is used to trap and handle errors in the formula. An error may occur here when trying to extract a value whose position is greater than $n$.

To illustrate this example, the system shown in Figure 12 will be used.

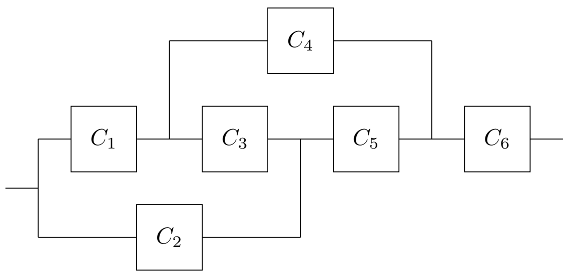



**Figure 12.** Complex system to illustrate the event space method.

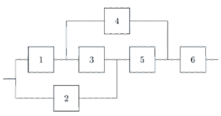
The most tedious task is to complete the state (system working or failing) for each combination. One method to quickly capture these states is to determine (minimal) paths that constitute success. A path is a set of components such that if all components are working, there is a path between the input and output of the system. A path is said to be minimal if it does not contain any other path. In other words, a path is considered minimal if the failure of a single component of the path causes the system to fail.

‡https://support.microsoft.com/en-us/office/mid-function-2eba57be-0c05-4bdc-bf81-5ecf4421eb8a
§https://support.microsoft.com/en-us/office/value-function-257d0108-07dc-437d-ae1c-bc2d3953d8c2
¶https://support.microsoft.com/en-us/office/iferror-function-c526fd07-caeb-47b8-8bb6-63f3e417f611

To facilitate the completion, a methodology consists of determining all the minimal paths. Then for each of them, filter the corresponding components by choosing the value 1 and put the state of the system to working. States that do not match any minimal path are set to failing.

For example, for the complex system given in Figure 13, one of the minimal paths corresponds to the set of components {2,5,6} (see Figure 14). The other two minimal paths correspond to the sets {1,4,6} and {1,3,5,6}.

Example



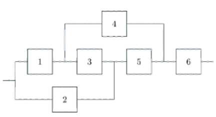

| Number of components | 6 |
|---|---|
| Reliability | 0,8453 |

| Components Id | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Components Name | 1 | 2 | 3 | 4 | 5 | 6 | |
| | VRAI | VRAI | VRAI | VRAI | VRAI | VRAI | FAUX |
| Reliability | 0,70 | 0,73 | 0,76 | 0,79 | 0,82 | 1,00 | |

| Mutually exclusive events | | Mutually exclusive events | Probability | State | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 000000 | ¬1 ¬2 ¬3 ¬4 ¬5 ¬6 | 0 | ↓ | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 000001 | ¬1 ¬2 ¬3 ¬4 ¬5 6 | 0,00073483 | ↓ | 0 | 0 | 0 | 0 | 0 | 1 |
| 2 | 000010 | ¬1 ¬2 ¬3 ¬4 5 ¬6 | 0 | ↓ | 0 | 0 | 0 | 0 | 1 | 0 |
| 3 | 000011 | ¬1 ¬2 ¬3 ¬4 5 6 | 0,00334757 | ↓ | 0 | 0 | 0 | 0 | 1 | 1 |
| 4 | 000100 | ¬1 ¬2 ¬3 4 ¬5 ¬6 | 0 | ↓ | 0 | 0 | 0 | 1 | 0 | 0 |
| 5 | 000101 | ¬1 ¬2 ¬3 4 ¬5 6 | 0,00276437 | ↓ | 0 | 0 | 0 | 1 | 0 | 1 |
| 6 | 000110 | ¬1 ¬2 ¬3 4 5 ¬6 | 0 | ↓ | 0 | 0 | 0 | 1 | 1 | 0 |
| 7 | 000111 | ¬1 ¬2 ¬3 4 5 6 | 0,01259323 | ↓ | 0 | 0 | 0 | 1 | 1 | 1 |
| 8 | 001000 | ¬1 ¬2 3 ¬4 ¬5 ¬6 | 0 | ↓ | 0 | 0 | 1 | 0 | 0 | 0 |
| 9 | 001001 | ¬1 ¬2 3 ¬4 ¬5 6 | 0,00232697 | ↓ | 0 | 0 | 1 | 0 | 0 | 1 |
| 10 | 001010 | ¬1 ¬2 3 ¬4 5 ¬6 | 0 | ↓ | 0 | 0 | 1 | 0 | 1 | 0 |
| 11 | 001011 | ¬1 ¬2 3 ¬4 5 6 | 0,01060063 | ↓ | 0 | 0 | 1 | 0 | 1 | 1 |
| 12 | 001100 | ¬1 ¬2 3 4 ¬5 ¬6 | 0 | ↓ | 0 | 0 | 1 | 1 | 0 | 0 |
| 13 | 001101 | ¬1 ¬2 3 4 ¬5 6 | 0,00875383 | ↓ | 0 | 0 | 1 | 1 | 0 | 1 |
| 14 | 001110 | ¬1 ¬2 3 4 5 ¬6 | 0 | ↓ | 0 | 0 | 1 | 1 | 1 | 0 |
| 15 | 001111 | ¬1 ¬2 3 4 5 6 | 0,03987857 | ↓ | 0 | 0 | 1 | 1 | 1 | 1 |
| 16 | 010000 | ¬1 2 ¬3 ¬4 ¬5 ¬6 | 0 | ↓ | 0 | 1 | 0 | 0 | 0 | 0 |
| 17 | 010001 | ¬1 2 ¬3 ¬4 ¬5 6 | 0,00198677 | ↓ | 0 | 1 | 0 | 0 | 0 | 1 |
| 18 | 010010 | ¬1 2 ¬3 ¬4 5 ¬6 | 0 | ↓ | 0 | 1 | 0 | 0 | 1 | 0 |
| 19 | 010011 | ¬1 2 ¬3 ¬4 5 6 | 0,00905083 | ↑ | 0 | 1 | 0 | 0 | 1 | 1 |
| 20 | 010100 | ¬1 2 ¬3 4 ¬5 ¬6 | 0 | ↓ | 0 | 1 | 0 | 1 | 0 | 0 |
| 21 | 010101 | ¬1 2 ¬3 4 ¬5 6 | 0,00747403 | ↓ | 0 | 1 | 0 | 1 | 0 | 1 |
| 22 | 010110 | ¬1 2 ¬3 4 5 ¬6 | 0 | ↓ | 0 | 1 | 0 | 1 | 1 | 0 |
| 23 | 010111 | ¬1 2 ¬3 4 5 6 | 0,03404837 | ↑ | 0 | 1 | 0 | 1 | 1 | 1 |
| 24 | 011000 | ¬1 2 3 ¬4 ¬5 ¬6 | 0 | ↓ | 0 | 1 | 1 | 0 | 0 | 0 |
| 25 | 011001 | ¬1 2 3 ¬4 ¬5 6 | 0,00629143 | ↓ | 0 | 1 | 1 | 0 | 0 | 1 |
| 26 | 011010 | ¬1 2 3 ¬4 5 ¬6 | 0 | ↓ | 0 | 1 | 1 | 0 | 1 | 0 |
| 27 | 011011 | ¬1 2 3 ¬4 5 6 | 0,02866097 | ↑ | 0 | 1 | 1 | 0 | 1 | 1 |
| 28 | 011100 | ¬1 2 3 4 ¬5 ¬6 | 0 | ↓ | 0 | 1 | 1 | 1 | 0 | 0 |
| 29 | 011101 | ¬1 2 3 4 ¬5 6 | 0,02366777 | ↓ | 0 | 1 | 1 | 1 | 0 | 1 |
| 30 | 011110 | ¬1 2 3 4 5 ¬6 | 0 | ↓ | 0 | 1 | 1 | 1 | 1 | 0 |
| 31 | 011111 | ¬1 2 3 4 5 6 | 0,10781983 | ↑ | 0 | 1 | 1 | 1 | 1 | 1 |
| 32 | 100000 | 1 ¬2 ¬3 ¬4 ¬5 ¬6 | 0 | ↓ | 1 | 0 | 0 | 0 | 0 | 0 |

**Figure 13.** Illustrative example of the event space method.

Example




| Number of components | 6 |
|---|---|
| Reliability | 0,7608 |

| Components Id | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Components Name | 1 | 2 | 3 | 4 | 5 | 6 | |
| | VRAI | VRAI | VRAI | VRAI | VRAI | VRAI | FAUX |
| Reliability | 0,70 | 0,73 | 0,76 | 0,79 | 0,82 | 0,90 | |

| Mutually exclusive events | | Mutually exclusive events | Probability | State | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 010011 | ¬1 2 ¬3 ¬4 5 6 | 0,00814575 | ↑ | 0 | 1 | 0 | 0 | 1 | 1 |
| 23 | 010111 | ¬1 2 ¬3 4 5 6 | 0,03064353 | ↑ | 0 | 1 | 0 | 1 | 1 | 1 |
| 27 | 011011 | ¬1 2 3 ¬4 5 6 | 0,02579487 | ↑ | 0 | 1 | 1 | 0 | 1 | 1 |
| 31 | 011111 | ¬1 2 3 4 5 6 | 0,09703785 | ↑ | 0 | 1 | 1 | 1 | 1 | 1 |
| 51 | 110011 | 1 2 ¬3 ¬4 5 6 | 0,01900675 | ↑ | 1 | 1 | 0 | 0 | 1 | 1 |
| 55 | 110111 | 1 2 ¬3 4 5 6 | 0,07150157 | ↑ | 1 | 1 | 0 | 1 | 1 | 1 |
| 59 | 111011 | 1 2 3 ¬4 5 6 | 0,06018803 | ↑ | 1 | 1 | 1 | 0 | 1 | 1 |
| 63 | 111111 | 1 2 3 4 5 6 | 0,22642165 | ↑ | 1 | 1 | 1 | 1 | 1 | 1 |
| 64 | | | | | | | | | | |

**Figure 14.** Set of all paths including the minimal path {2,5,6}.

### 4.4. Practical exercises

To ensure that students understand the different methods proposed, the spreadsheet provides three exercises, one for each method.

For the reduction method, the main difficulty for the student will be to determine the reliability of a 2-out-of-3 system, where each component has a different reliability. To do this, they will have to be inspired by the approach used for the $k$-out-of-4 system (see Figure 9).

For the decomposition method, the exercise is based on the system illustrated in Figure 12. The particularity of this system requires the use of two key components.

Finally, the exercise of the event space method is hijacked from its initial function by seeking to estimate the reliability of a system of $k$-out-of-$n$ whose component reliabilities are different. In this case, the states where the system works are conditioned by the number of operational components ($\geq k$).

## 5. Conclusions and perspectives

### 5.1. Discussion

Thanks to the reading of this article as well as the practical work proposed throughout it, the students will have been able to progress in their understanding of the reliability of industrial systems. The classic formulas learned during the lessons are recalled and directly applied in the software. This direct link between theory and its application is of great interest for a better understanding. The spreadsheets resulting from this work calculate the possible associations of components. The linear progression in difficulty leads the reader to first understand a series and a parallel association to correctly handle the fundamental notions. Then, the $k$-on-$n$ systems are introduced and the three major methods used to assess the reliability of the systems are explained to lead the readers to carry out their calculation in a traditional spreadsheet.

For students, the major results to expect are the following. First, the sheets available next to this paper put the theory into practice using the different formulas learned in classic courses and allow both to check a good understanding of the concepts and to deepen their knowledge. Then, the feeling of "freedom" felt by the pupils is put to the benefit of their curiosity. Some of them claim to have worked more on this project than on any other thanks to this relative freedom. Moreover, they are proud that they managed to create a useful tool on their own, without any possibility of error after a serious check. Thus, they are strongly encouraged to create new files for very different problems in the future. Likewise, they acknowledge having acquired a new way of working.

This article gives out-of-the-box teaching materials for the dreaded next rushed transition to emergency remote learning, responding to a point raised by Tsai et al. [30].

### 5.2. Conclusions

In this paper, a digital technological tool is proposed to better prepare the teaching methods that will make it possible to better face the next global crisis of the COVID-19 type, to teach the calculation of reliability of systems thanks to a classic spreadsheet. Moreover, the base file is given alongside this paper, so that any reader can progress in this work, remotely, asynchronously and autonomously thanks to the help of the instructions given.

We prove that at least two researchers design such practical work today, both with the aim of advancing students in a given subject and improving the modeling of the general population. The possibilities offered by such a paper are indeed infinite, and we deeply hope that this paper will continue to encourage the foundation of a research path towards the objective of capitalizing knowledge in many fields, as well as their teaching and modeling opportunities.

### *5.3. Managerial implication*

The managerial implications of this paper are twofold. The first is that staff managers (industrial managers or educational managers) will be able to rely on this work to improve the training of their staff. The second deals with the management of the education during global lockdowns, forcing the entire population to stay away from training rooms. The first time was surprising and traumatic, but this paper and the following ones will help to do better in future crises.

### *5.4. Practical/social implications*

The practical and social implications are the better education level of the concerned population. The students that will benefit from the proposed training will deepen their knowledge, both on spreadsheet software modeling and on industrial systems reliability calculation, without the need of registering on more or less expensive university or professional formation modules.

The scientific value of this paper consists of a clear and directly usable reliability model, and the direct applicability of the spreadsheet resulting from each reader's work. The novelty of this work is that in the era of Google and AI providing lots of data on a given subject, it gives a concise, comprehensive, pedagogically professionally made, serious help in the progression of the students. This prevents them from getting lost in all these digital meanders, as the readers only have to follow the progressive work proposed in this paper. This intention is really new compared to all the existing studies.

### *5.5. Limitations and future research*

The limitations that can be found in this paper are the following: The classic disadvantages of distance education are all broadly applicable to the project proposed in this article. Here, we can mainly recall the worst ones: Technological obstacles, exacerbated and amplified social and educational inequalities [31], and mental health problems.

Another limitation relates to the limits of a model itself. In essence, a model is strictly able to model only what it is supposed to do. We all need to be aware of this reality. One of the objectives of this paper is to give students and readers the keys to modeling and calculating the reliability of any industrial system they will encounter during their professional life.

In recent decades, the role of digital technology in seasonal demand forecasting methods has taken on increasing importance, and we intend to explore this point in our future research. For example, we will explore the dependence of system reliability on demand. As the demand on industrial production systems is more easily predictable, their relative reliability calculation will likely be easier to calculate. This article allows them to be calculated statically, but we intend to work on another article on the dynamic calculation.

Another line of research concerns the *variation of modeled data*. For example, concerning the practical work presented in this paper, after having modeled a complete industrial system, it could be interesting to propose a continuation of this spreadsheet consisting in varying the reliability values in their confidence intervals. Thus, it would be interesting to illustrate the effects generated by uncertainty on reliability values. This is not the purpose of this first paper, but this line of research seems interesting, for engineering degrees for example. Similarly, pedagogical papers at the "intermediate" and "expert" levels could be considered to complete this founding article on the subject. As concluded in the first paper of the collection, the possibilities are endless.

Other lines of future research in this first work on the teaching, modeling and computer science of industrial reliability systems, could concern any subject relating to engineering sciences. For example, a power electronics simulator is currently being tested, as well as an induction motor modeling lab. Additionally, a probabilistic mathematical simulator is already in use in our university classrooms with very enthusiastic use from students, and is also being considered for future submission. Automatic control and thermal engineering issues are also taken into account for future medium-term publications.

## Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

## Conflict of interest

The authors declare no conflicts of interest.

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**Supplementary**

The following supporting information can be downloaded at: `http://aimspress.com//aimspress-upload/article_attachments/math/202382925956106.xlsx`