EXCEL-BASED ANALYSIS AND DYNAMISATION OF PROBABILITIES FOR LOGISTICS PLANNING

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ABSTRACT

The existing parameters for the planning of logistics support as given in the guidelines for logistics planning at Brigade level and similar guidelines at Battalion level include a huge amount of (fixed) probabilities. These probabilities were derived from historical data. Because of this, these parameters are questioned during war-games, due to the fact that logistics officers' own experiences show different results in certain real-life cases. This paper deals with these parameters and how Excel-based spreadsheets are used to explain the different values, supporting them once the statistical laws of large numbers have been achieved. In addition, it shows how such spreadsheets can be used for situations where a small number (below the afore-mentioned laws) needs to be investigated for logistics purposes.

Keywords: Logistics Planning, Excel-based Probabilities, Law of Large Numbers, Spreadsheet-based Simulation

1. INTRODUCTION

Logistics planning in the Austrian and various other European armed forces, as well as in the US, are based on the Day of Supply (DOS) approach. Certain figures are predetermined for the appropriate planning of different units concerning daily demands with respect to water, food, ammunition, fuel and various other parameters. (Austrian Ministry of Defence and Sports, 2010)

These figures were derived from historical conflicts, using operations research approaches to shape future demands (Shrader 2006; Shrader 2008; Shrader 2009), and are used in the education and training of supply sergeants. The parameters are definite numbers, albeit changed as appropriate by multiplicative factors according to terrain, weather conditions and mission intensity.

For the US Navy, an accurate planning of logistics was of great importance even in the early 1970s, when logistical implications started to be implemented in computer-based war-games. (Perla, 1990)

However, this DOS approach is already being questioned in the US itself, where, in 2008, an article suggested changing to a demand-oriented "Sense and Respond Logistics" approach, reducing the stockpile from 60 days for the Operation Desert Storm in 1991 to 5- 7 days for the Operation Iraqi Freedom in 2003. (Hammond 2008). This approach may alter the existing view on logistics, as given, for example, in the NATO Logistics Handbook and subsequent related documents. (NATO 2007). Nevertheless, the DOS-based logistics planning approaches are still taught to Austrian as well as foreign officers participating in the appropriate courses.

On the other hand, the above-mentioned Austrian guidelines for logistics planning contain a warning notice "Just applying the guidelines without taking the current situation into account will lead to results that are not applicable to the supply officer". The question still remains as to how these responsible officers should become aware of inappropriate conditions, if these general parameters no longer apply.

Austria faces the challenging task of being the "Logistics Lead Nation" for the European Battle Group during the second half of 2012. For a common multinational planning and information interchange, the DOS-based approach is still the basis for all calculations.

With respect to the current different international missions of the Austrian Armed Forces, there are several challenges to proper supply planning still to be overcome, which are described in more detail in the next section.

2. CHALLENGES TO LOGISTICS PLANNING

Among the various DOS parameters which calculate the average demand for different goods several parameters exist for risks of failure or damage, including to vehicles, which will now be taken as examples. Two main aspects will be investigated in more detail, summed up in the well-known bathtub curve derived from reliability engineering. (Matyas 2010)

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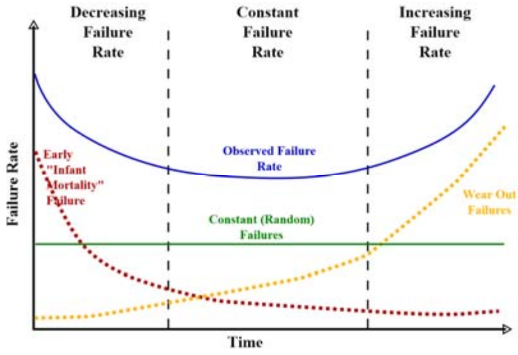


Figure 1: Bathtub curve (Wikipedia, 2009)

Especially the figures given for the failure of systems suggest that this rate remains constant during the whole lifetime of these systems, which does not hold true in different cases.

2.1. An example of the increased risks of early failure

In 2008, the Austrian Armed Forces created a "Special Operations Vehicle" for the EUFOR Chad Mission. This development was based on the existing cross-country vehicle platform Puch G 290 (the Austrian brand of the Mercedes G series) called "Sandviper" and was carried out by the Austrian Armed Forces internal agency for arms and defence technology.

Due to the fact that these significant changes were implemented purely for this mission, long-term experiences with the failure of operations could not be gained when this vehicle was put to daily use in Africa. Even taking into consideration the fact that the agency was reducing the technical parts to the absolute minimum, it is important to apply an increased early failure rate, also because no experiences with this vehicle have been made in a desert zone.

Figure 2: The Puch G 290/LP “Sandviper” (Austrian Armed Forces Photograph 2011)

2.2. An example of the increased risks of wear-out failure

On the other hand, Austria is still using the Aérospatiale Alouette III helicopter, which was first introduced in 1960 and has already been withdrawn in various other states (France 2004, Ireland 2007, Switzerland 2010, among others).

This helicopter, which has been in service in Austria since 1967, is also part of the Austrian missions to Bosnia, as well as sometimes to Kosovo, supporting the EUFOR and KFOR, respectively. Due to the age of the equipment, normal parameters for the failure of parts are not likely to apply any more.

Figure 3: The Aérospatiale Alouette III (Austrian Armed Forces Photograph 2011)

2.3. The problem of limited amounts not fulfilling the law of large numbers

As already mentioned, a couple of vehicles are used in daily operation outside Austria. This, as well as specific equipment available only in limited amounts (e.g. armoured recovery vehicles), alters the pure algorithmic approach for calculating the amount of spare parts and the average number of vehicles available, as well as for appropriate planning. This change is based on the statistical law of large numbers, which is not fulfilled in various cases, especially concerning the technical equipment in use.

3. THE MATHEMATICAL APPROACH TO CHALLENGES IN LOGISTICS PLANNING

Especially with respect to the given probabilities, an algorithmic calculation of the amount of failures and the damage to vehicles divided into two categories (normal and armoured vehicles) under certain operational conditions does not correspond to reality (computing not purely integer numbers) or to the failures observed.

3.1. The Bernoulli distribution and a first spreadsheet model

The probabilities of failure or damage during an operation are given as a percentage. For example, a 6% probability needs to be taken into account for armoured vehicles during a one-day march under normal conditions. Assuming an armoured infantry with 14 infantry fighting vehicles (IFV), the algebraic result of calculating the number of vehicles affected at the end of the day is 0.84.

If two vehicles fail during the day, the calculation method that has already been called into question and the underlying parameters not providing integer numbers can be completely rejected.

To illustrate what is meant by a mathematical Bernoulli distribution (i.e. throwing a coin, falling on one side with a given probability), a first basic Excel sheet can be created to start a so-called "spreadsheet-based simulation approach", according to (Schriber 2009).

Table 1: Random determination of failures according to the given probability

IFV No.	Random Probability	in Operation / Failure
1	0.851195351	in Operation
2	0.556390769	in Operation
3	0.054002108	FAILURE
4	0.028278218	FAILURE
5	0.672174937	in Operation
6	0.363501829	in Operation
7	0.344775482	in Operation
8	0.234264572	in Operation
9	0.237118103	in Operation
10	0.029055798	FAILURE
11	0.512215943	in Operation
12	0.032268999	FAILURE
13	0.060050503	in Operation
14	0.737855443	in Operation
Number of failures:		***4***

Table 1 shows the vehicle number in the left-hand column, a randomly generated number between 0 and 1 in the central column and the assessment of the parameter in the right-hand column. Every randomly generated number less than or equal to 0.06 is assumed to be a failure at the end of the day. The number of failures is calculated at the end of the table. A new scenario is generated by pressing the "F9" button on the keyboard.

In most cases, the number of failures is 1, sometimes decreasing to 0 and, more rarely, increasing to 2 or even 3 and rarely to 4. A certain sequence of 20 computed scenarios counting the number of failures may be the following:

2, 0, 1, 0, 2, 1, 0, 1, 1, 0, 0, 1, 1, 2, 1, 1, 3, 0, 2, 0

which means:

- 7 times no failure
- 8 times one failure
- 4 times two failures
- 1 time three failures

It then becomes clear that simply an algebraic calculation of given probabilities using the given small amount of vehicles taken into account in the case of small numbers is not sufficient and that a failure rate of up to three vehicles does not necessarily mean that the given parameter is wrong, even though the percentage of failures in this case rises to 21-43%.

3.2. The Poisson distribution and the confidence interval

Given this result, it becomes clear that uncertainty as regards planning first increases. The question "How many vehicles do I need to take into account then?" is soon raised.

This is how the Poisson distribution – and in this particular case subsequently also a higher time resolution – is introduced.

Given the parameter of 0.84 failures per day (viewed statistically), the Poisson distribution can be calculated, again using Excel:

Table 2: Calculation of (cumulative) probabilities for vehicle failures

Number of IFV vehicles	Probability, that this number of vehicles fails	Probability, that maximum this number of vehicles fails
0	43.17%	43.17%
1	36.26%	79.43%
2	15.23%	94.67%
3	4.26%	98.93%
4	0.90%	99.83%
5	0.15%	99.98%
6	0.02%	100.00%

Here, it can easily be seen that the results gained before have been verified. With a 95% or 97.5% confidence, up to three vehicles need to be repaired. On the other hand, in terms of fuel support, all the vehicles need to be taken into account.

This result becomes even more interesting when it is discretized on a two-hourly basis. With respect to the new time intervals the failure probability per two hours is 0.07 (=0.84/12). The corresponding table is as follows:

Table 3: Calculation of (cumulative) probabilities for vehicle failures on a 2h basis

Number of IFV vehicles	Probability, that this number of vehicles fails	Probability, that maximum this number of vehicles fails
0	93.24%	93.24%
1	6.53%	99.77%
2	0.23%	99.99%
3	0.01%	100.00%

Assuming a certain reliability (in this case, 95%, 97.5% or 99% leads to the same results), the loss of one vehicle needs to be taken into account.

The following graph shows the computed borderlines for the development of the number of vehicles:

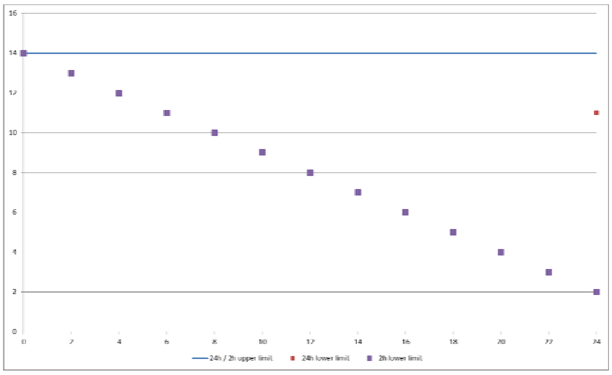


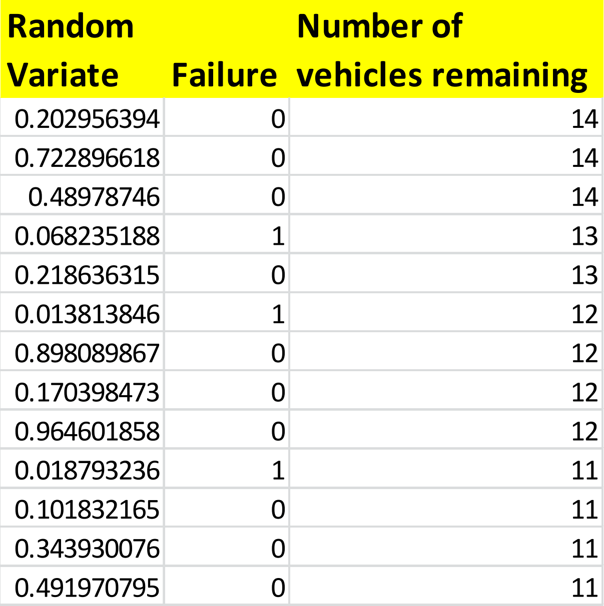
Figure 4: Illustration of the development of the number of vehicles over a 24h approach vs. a 2h approach

3.3. A spreadsheet-based simulation approach

Nevertheless, to come back to the Bernoulli distribution, a spreadsheet-based simulation approach can now be integrated.

A scenario is computed, where, on the given two-hourly basis, the number of vehicles during the day is calculated. Again, a row with random variates is taken and assessed against the probability:

Table 4: Preparation of the spreadsheet approach



Random Variate	Failure	Number of vehicles remaining
0.202956394	0	14
0.722896618	0	14
0.48978746	0	14
0.068235188	1	13
0.218636315	0	13
0.013813846	1	12
0.898089867	0	12
0.170398473	0	12
0.964601858	0	12
0.018793236	1	11
0.101832165	0	11
0.343930076	0	11
0.491970795	0	11

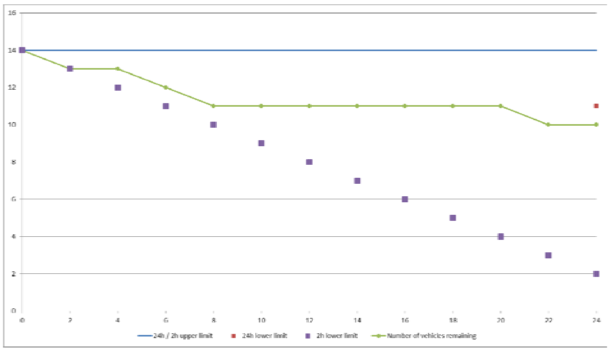


Figure 5: Development of the number of vehicles - graphical illustration

Again, by pressing F9, different scenarios are computed, which in general result in somewhere between 11 and 14 vehicles remaining.

3.4. Destruction / failure analysis of a large number of vehicles

With respect to the large number of vehicles used, as trained at Brigade level, this approach can be scaled up to a larger number of armoured vehicles.

A probability of 20% destruction was assumed for combat vehicles. Taking 394 combat vehicles into account, the application of the Poisson distribution gives the following picture:

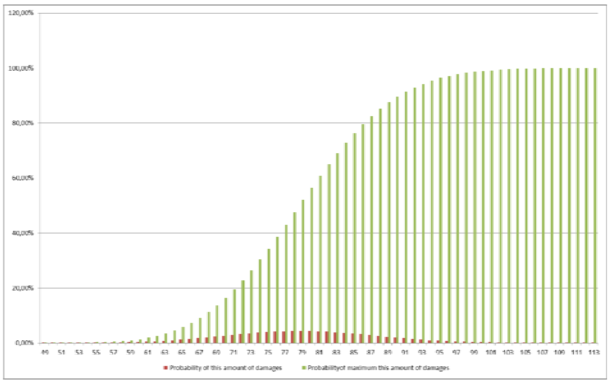


Figure 6: Increasing the number of vehicles, motivating the density and distribution function

This purely Microsoft Excel-based analysis implies that, in contrast to the given estimate of around 79 destroyed vehicles, the amount of remaining vehicles may be somewhere between 62 and 97, with a 95% probability for the confidence interval, and between 51 and 110 vehicles, assuming a 99% probability.

These new figures, which differ from the 79 destroyed combat vehicles (the probability of achieving this number is just 4.5%), are the basis for further risk analysis at different levels.

From the supply side, it should be assumed that only a small amount of vehicles has been lost and therefore personnel, material and fuel needs to be provided, ending up with just 14.5% in terms of losses.

On the other hand, further attack or defence capabilities need to assume that the maximum amount will not be available after one day of combat. In this case, one is faced with a 5.6% increase in effort for dressing stations, the search and rescue tasks of personnel and, finally, the salvaging and recovery of materials.

Due to the fact that only integer numbers can realistically be used, the same parameters are used for an hourly-based analysis of destruction or other failures (formerly this was done on a daily basis). For this, the given parameters are converted into average failures per hour and are applied in a similar manner to that already shown.

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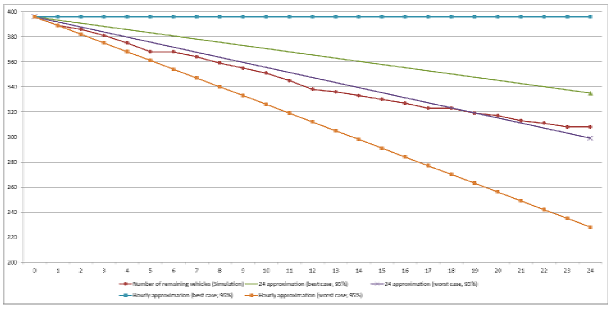

Figure 7: Hourly-based destruction /failure analysis, again including a simulated scenario

While the 24-hour approximation is still illustrated with the straight lines ending up with an hourly-based analysis, this shows a realistic development.

In this case, the red line with the dots illustrates – so to say – an Excel-based simulation of destruction, nearly always ending up within the limits of the daily estimates, but nevertheless often crossing the imaginary borders during these 24 hours.

This clearly illustrates how probabilities are balanced and try to converge to the algebraic mean, just as the strong law of large numbers is mathematically proven. In addition, it leads to a better understanding of how the Austrian war-game simulation environment “FüSim” internally may realise this kind of randomness, bringing staff officers closer to topics of random variates, from the simulation point of view.

4. PLANNING IMPACT

There are several impacts on planning which are briefly described below.

4.1. Saving and rescuing

During a mission, a certain amount of additional consequences need to be taken into account. One of these is to rescue a minimum of 50% of the heavily armoured vehicles for future repair and use. The hourly graph shows the impact of such additional requirements on the planning of the necessary equipment.

4.1. Calculation of the necessary supply and available forces

Based on the 24-hour expectations, the lower and upper boundaries now illustrate for how many forces the resupply of goods needs to be provided, assuming the best case scenario that a maximum amount has survived.

4.2. Overestimation due to uncertainty

Already in this case, an overestimation is likely to be reduced. Only this amount, which is necessary even in the worst case, will be provided for a mission so that further equipment and material exceeding the maximum necessary amount can be avoided.

The effect gained is to reduce the necessary amount to be transported, stored, observed and finally shipped back to the original destination.

4.3. Assessment of planning parameters

Finally, the graphical results can also be applied to assess the real figures, which are provided from time to time. Especially in the event that the lower (hourly) limits are overstepped, planning parameters need to be questioned immediately, because they do not hold true anymore.

5. SUMMARY AND OUTLOOK

The importance of this kind of analysis is also borne out by the new challenges of irregular warfare, where existing parameters from former wars between armed forces cannot be applied any more. It provides a first approach to risk analysis, when developments from the real world start to differ from planning calculations.

This kind of mathematical analysis is becoming increasingly important in the training of Austrian staff officers. Therefore, a dedicated Operations Research Course including this kind of analysis will be provided for the education of Austrian staff officers from autumn 2011 on.

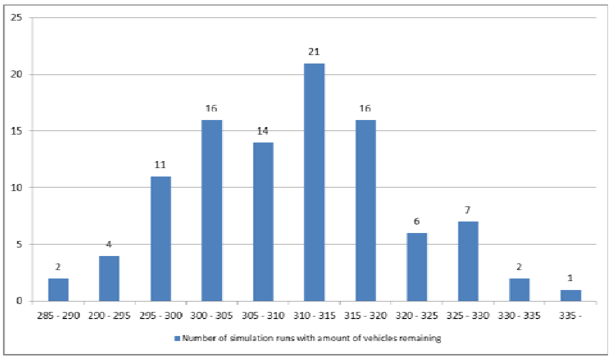

Figure 8: Excel-based histogram of 100 scenarios basing on the model of chapter 3.4

If one looks at this figure, it becomes clear that the average failures are the most likely, but it also gives a clear picture of how this may vary in such a case. Based on this figure, as well as on Figure 6, it becomes easier to introduce statistical distribution and density functions.

This approach is also the basis for using further software such as @RISK, which provides a certain amount of distribution functions that can already be approximated by a small Excel-based macro.

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