Is Reliability Theory Still Alive?

Igor Ushakov

At the banquet held during closing of the MMR-2004 Conference (Santa Fe, USA), one of the most prominent specialists on Reliability Theory, Professor of The George Washington University Nozer Singpurwalla was a host of the discussion during the dinner.The topic he chose was a bit provocative: "IS RELIABILITY THEORY STILL ALIVE ?" Even the question itself led to a furious reaction of the conference participant: "Yes! It is alive! It is flourishing!"

What is going now if even such a question was suggested to the audience by such a serious mathematician who dedicated all his talent to developing Reliability Theory?

It seems to me that Professor Singpurwalla is right asking such a question. Though an answer to this question is not so simple. Being in a position a "mammoth" (if not a dinosaur ☺) in Reliability Theory, I take a brevity to discuss this difficult question.

Factors That Determined in the Past and Determine Now Reliability Theory

1. A theory always germinates in the depth of practical problems.

Let us recollect when the first boom of Reliability Theory happened. It was the Korean War time (1950-53). Military equipment of the both opposing sides developed in the years of the "Cold War" very intensively: Soviet and American hawks competed at armament race. Equipment became more and more sophisticated, more and more complex and – as a result – more and more unreliable. Both sides lose huge money due to unreliability, and of course Americans were the first who began to develop Reliability Theory: they always could count money better.

First, the US engineers paid more attention to quality control, reliability engineering and maintenance. Institute of Radio Engineers (IRE) and later Institute of Electrical and Electronics Engineers (IEEE) called annual Symposiums on Reliability and Quality Control (R&QC) and published Proceedings. At the beginning of 60s, a real tsunami of publication on reliability hit the engineering communities...

A little later (as usual!) activity in this area began in the former Soviet Union. Academician Axel Berg coined a phrase: "Reliability is the problem number №1 !'

Thus, there appeared the problem that had to be solved fast and efficiently.

2. Decreasing interest to Reliability Theory.

First reason is objective: equipmen noe is much more reliable than earlier. If vacuum lamps in electronic equipment in 50-60s had MTTF about at most hundreds hours, today's microchips that can perform much more complex operations have failure rate 10^{-8} 1/h and less.

It is clear that reliability problems moved to the system level rather than component level.

3. Oversaturation of the "scientific market".

A theory should always go ahead of needs of practice. Otherwise it will take a hand on tha pulse of a dead man ☺... However, one can say that modern reliability theory ran too far from practical engineering needs or even went to dead ends of "exotic" and practically useless mathematical exercises. Actually, practical reliability engineering has enough first class solution for today's problems. New "local" problems can be solved on the local levels.

Probably, for engineering companies, it is more effective way to solve current reliability problems id to invite specialists on a contract basis.

4. Beginning "theory for theory".

If you take a look at the first works on reliability of the end of 50s and of the beginning of 60s, you could see pure pragmatic nature of those works. Even "pure mathematicians" wrote for users rather than for themselves: their results were transparent and their applicability was evident. However, in the middle of 70s there appeared papers considering unrealistic models, math results began to be non-understandable with no common sense interpretation.

That situation led to definite discredit of Reliability Theory as a whole. This situation was expressed by one of leading specialist in reliability engineering: "The reliability Theory is for those who understand nothing in reliability. Those who understand reliability, they design and produce reliable equipment!"

(Unfortunately, such position led to a catastrophe with Soviet "Soyuz-1" when due to a failure at the cabin sealing three Soviet astronauts died during landing: Sputnik's designers forgot that relay schemes have two types of failures: false opening and false closing.)

Nevertheless, indeed, pragmatism of theoretical reliability works went down dramatically...

5. Aspects of "modern fashion" in technology.

Once I asked my old friend Robert Machol, who is known for his book "System Engineering", why did a new direction "Management Science" appear? Initially, it was Cybernetics, then Operations Research has been coined, and now we have Management Science… "You already answered on your own question: this is a problem of fashion changing! Who will pay for an old dress? It is assumed that new is better than old!" – answered Machol.

Of course, it was a joke though, as it said, any joke contents a *bit of joke*.

6. Moving a "center of gravity" of the problem.

At its first steps, Reliability Theory paid its main attention to problems od field data gathering methodology and data inference. In the modern theory the system analysis became the main topic. At the same time, giant technological systems like telecommunication, transportation, computer networks or oil and gas distributing systems need specific methods rather than general ones. Very often a solution for one particular type of the system is absolutely inapplicable for another. However, any specific solution is based on the fundamental results of common reliability theory.

Thus, as Marc Twain said, the hearsay about the death of reliability are premature, though the age of its flourish doubtlessly is behind...

Reliability Works in the Former Soviet Union

In the end of 50s there appeared first publications on reliability, and in 1958 the First All-Union Conference on Reliability took place in Moscow.

Informal scientific groups began to form in Moscoe, Leningrad, Kiev and Riga...

Moscow school of Reliability.

First group was formed in Zhukovsky (B. Vasilyev, G. Druzhinin. M. Sinitsa)and one of the Military R&D Institute of Defense Ministry (V. Kuznetsov, I. Morozov, K. Tsvetaev).

At the same time at the Popov Society, a brilliant manager Jacov Sorin organized Reliability Chapter where the main role played R. Levin. Then in 1959 J. Sorin established the very first Reliability Department at one of the industrial institutes of the Military-IndustrialComplex of the former USSR.

From the very first days of the department existence, Academician Boris Gnedenko and Professors of the Moscow State University Alexander Solovyev and Yuri Belyaev collaborate with this department. A well known statistician – Jacov Shor from one of Military R&D Institutes joined them. Those scientists with J. Sorin and the first employee of the department Igor Ushakov became official consultants on reliability at the State Bureau on Standartization (Gosstandard) and later form the Scientific Counsil on Reliability.

In 1962 B. Gnedenko I J. Sorin established at the Moscow State University weekly Seminar on Reliability for engineers. It was a very popular event attended by tens of practical engineers. That Seminar was led by B. Gnedenko with help of A. Solovyev, Yu.Belyaev and I. Kovalenko.

Tandem "Sorin-Gnedenko" has been successfully existing about 25 years and has performed a huge organizational and educational work.

Approximately in a year, J. Sorin established Moscow Reliability Consulting Center, and as the Director of the Center appointed B. Gnedenko as a Scientific Lead of the organization and I. Ushakov as its Scientific Coordinator.

A number of Doctors of Sciences and Professors collaborated with the Center, among them A.Aristov, I. Aronov, Yu. Belyaev, B. Berdichevsky, E. Dzirkal, F. Fishbein, J. Shor, A. Solovyev, R. Ulinich, I. Ushakov, and others. They performed everyday's consulting for industrial engineers and twice a month there were tree 2-hour lectures. More than 50% of attendees were not from Moscow. They came from various arts of the former Soviet Union: Far East and Baltic Republics, Ukraine and Caucasus Republics.

In 1969 J.Sorin established the journal titled "Reliabiity and Quality Control" and became its first Editor, taking B. Gnedenko, J. Shor and I. Ushakov as his deputies.

Approximately at the same time, the Publishing House "Soviet Radio" (later "Radio and Telecommunication") established Editorial Council headed by B. Gnedenko. It began to publish series named "Library of ReliabilityEngineers". Books of the series played significant role in educating reliability engineers all over the former Soviet Union.

In the middle of 70s, a respectful academic journal "Technical Cybernetics" (translated and published in the USA as "Soviet Journal of Computer and System Sciences") established a special Section "Reliability Theory".

It is difficult to name all those who belong toe the Moscow reliability school, nevertheless I should mention A. Aristov, I. Aronov, V. Gadasin, Yu. Konyonkov, G. Kartashov, I. Pavlov, A. Rajkin, R. Sudakov, O. Tyoskin, V. Shper.

Talking about Moscow Reliability School, it is reasonable to mention two books that reflected many results in Reliability Theory.

First of all, it was an excellent book "Mathematical Methods in Reliability" by B. Gnedenko, Yu. Belyaev and A. Solovyev [1]. The book was translated into English [2]. Even now, 40 years after the publication, this book and the book by R. Barlow and F. Proschan book [3, 4] that was translated into Russian [5, 6], remain the best best monographs on the subject.

Secondly. It was "Handbook on Reliability" by B. Kozlov and I. Ushakov [7] that had several editions [8 – 9] and translations [10 – 14]. This handbook remainded many years a table book for reliability engineers.

Leningrad Reliability School.

In 1959 at one of Leningrad R&D Institutes of Shipbuilding Ministry has been established the first Reliability Department headed by I. Malikov. In the same year I. Malikov, A. Polovko, N. Romanov and P. Chukreev, who led the Leningrad Reliability School, published first Russian book "Fundamentals of Reliability Calculation" [15]. The book contained only 139 pages, but it was the first book where one could find systematic description of an elementary knowledge in reliability theory.

Soon in Leningrad A. Polovko founded Leningrad Reliability Center.

In 1964 A. Polovko published the very first monograph on Perliability Theory [16] that was the first Russian book on the subject translated into English [17].

Leningrad Reliability School gave several significant names: G. Cherkesov, L. Gorsky, I. Ryabinin, N. Sedyakin, I. Shubinsky and others.

Kiev Reliability School.

In Kiev Military Radio Engineering Academy flourished a group headed by N. Shishonok: L. Barvinsky, B. Kredentser, M. Lastovchenko, A. Perrote, V. Repkin, S. Senetsky. Under Shishonok's editorial leadership it was published "Fundamentals of Reliability Theory for Electronic Equipment" [18].

In parallel, at Kiev State University and later in Cybernetics Institute appears a very strong group consisted mostly of pupils of B. Gnedenko. This group dealt with general stochastic processes theory applied to queuing and reliability problems. In this group there were such outstanding scientists like Academicians I. Kovalenko and V. Korolyuk, and such specialists like V. Anisimov, V. Volkovich, T.Maryanovich, A Turvin, V. Zaslavsky and others.

Riga Reliability School.

Founder od Riga Reliability School was Kh. Kordonsky who was a Chair of Department at Riga Instute of Civil Aviation. His pupils – A. Andronov, I. Gertsbakh and Yu. Paramonov.

Probably this group was specifically practice oriented. In 1963 Kh. Kordonsky published his book [19], in which some reliability models were discussed, then in 1969 I. Gertsbakh published his book [21], that is, probably, the best book on maintenance problem.

Kh. Kordonsky, following his Moscow and Leningrad colleagues open a regular seminar on reliability theory for engineers.

Independently at the same time in the same area V. Leontiev and V. Levin have been working.

Irkutsk Reliability School.

Reliability problems in Siberia were related mostly to energy systems. Director of Siberian Energy Instutute Academician Yu. Rudenko led those researches gathering a group of young scientists (N. Voropai, G. Kolosok, L. Krivorutsky, V Zorkaltsev and other). For the work related to survivability analysis of All-Union Energy system, Yu. Rudenko and I. Ushakov were honored by prestigious Academy of Sciences' Krzhizhanovsky Prize. They published together the first book on energy systems reliability [22, 23].

Famous Rudenko's Seminars in Baikal Lake area attracted not only by exotic place… Among participants there were such specialists like E. Chervony, Yu. Guk, N. Manov, E. Stavrovsky, M. Sukharev, E. Farkhad-Zadeh, M. Cheltsov, M. Yastrebenetsky and other.

Of course, the list could be continued: Tashkent, Gorky, Kharkov, Minsk, Tbilisi, Erevan and Vladivostok should be mentioned here.

Brief History of Development Reliability Theory in the Former Soviet Union

As already was mentioned, the first steps in Reliability Theory developing were done in the USA. However, Soviet statisticians and engineers bagan to work in that direction with a small delay.

This brief review does not target to be complete, though I believe that some analysis of theoretical ideas developed in the Soviet Reliability School should be done.

Interesting method of analysis of confidence estimates of system reliability based on non-failure tests of its components was suggested byR. Mirny and A. Solovyev [24]. Then some general results based on Monte Carlo simulation were obtained by Yu. Belyaev [25, 26]. Many new analytical results afterwards were obtained by I. Pavlov [27 – 29], R. Sudakov [30] and O. Tyoskin [31].

Many works were related to analysis of complex systems with degradation of the operational level (partial failures). Indeed, hardly a complex system might be characterized by simple binary criteria of type "yes-no" [32-34].

The profs of too limit theorem for stochastic point processes played significant role in further development of methods of analysis of repairable system.

First. Hungarian A. Renyi [35] proved theorem concerning asymptotical "sifting" of stochastic point process, and approximately at the same time G. Ososkov [36] proved theorem concerning asymptotical superposition of the processes of the same type. Afterwards Yu. Belyaev, B. Grigelionis and I. Pogozhev generalized those results. Their results permitted to develop convenient approximate practical methods for reliability analysis of vomplex repairable (renewable) systems [37].

B. Gnedenko [38, 39] was the first investigator of asymptotic methods of reliability analysis of repairable (renewable) systems I the beginning of 60-s. He considered a duplicated renewable system and proved that asymptotic distribution (under condition of "fast repair") of the system time to failure is exponential and does not depend on the distribution of the repair time. This work opened a new direction in Reliability Theory that was successfully developed, first of all, by I. [40 - 42] Kovalenko and A. Solovyev [43 - 46].

Interesting ideas of semi-Markov processes aggregation related to reliability problems were suggested by V. Korolyuk and A. Turbin [47 – 48], and afterwards these ideas were developed in a series of works [49 – 50]. Interesting applications to Reliability Theory contains in the works by V. Anisimov [51] and D. Silvestrov [52].

Methods of optimal redundancy were developed in [53 - 57]. Some results from these works were used for preparation of Military Standards.

Such important direction of Reliability Theory as accelerated testing appeared in the very beginning of activity of Soviet specialists on reliability. Here works by N. Sedyakin [58], I. Gertsbakh and Kh. Kordonsky, [59], G. Kartashov, A. Perrote and K. Tsvetaev [60] have to be mentioned first of all. Models od accelerated tests with time-dependent loading were considered by V. Bagdanavichus and M. Nikulin [61].

Concluding this brief review, it is necessary to mention an excellent book edited by B. Gnedenko [62], in which many results of Soviet School on Reliability Theory have been summed up.

* * *

Evidently, these brief notes could not mention everybody who made an input into Reliability Theory and its practical implementation. Moreover, such brief review almost always suffer from author's subjective viewpoint. Actually, writing such review is a very dangerous thing: the author can offend his friends and colleagues who appears out of the review…

The flow of publications in Reliability Theory is very intensive. A new generation of specialists in reliability can loose their orientation in these trouble waters of books and papers on the subject.

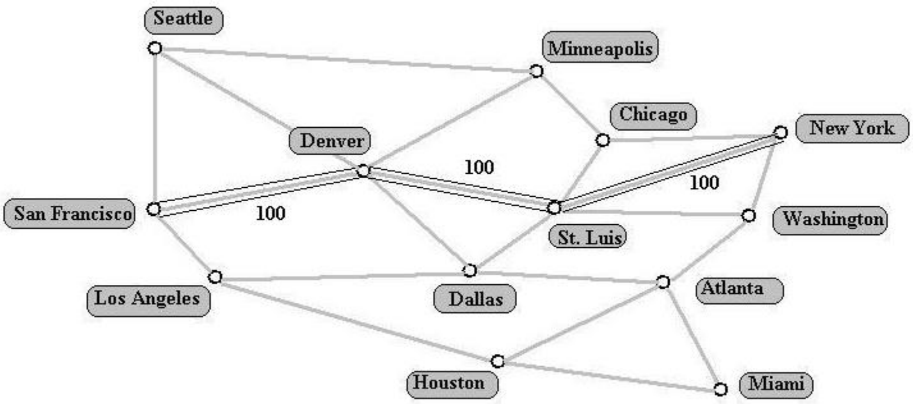
We have our Gnedenko Forum. Maybe it is reasonable to arrange rating of books on reliability?

Below I am presenting examples of some practical problems that I solved last years, working for several American companies.

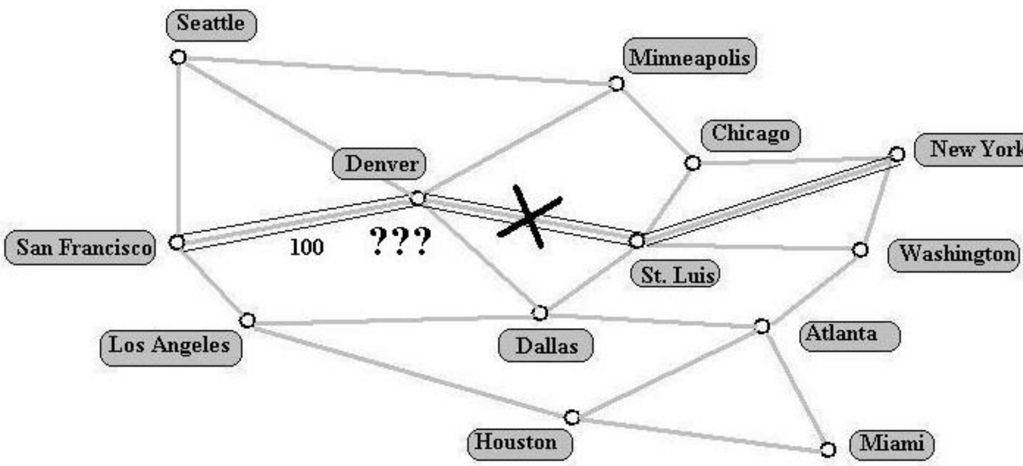
Examples of Solution of Practical Problems

Computer model of survivability analysis of the telecommunication network (for US company MCI)

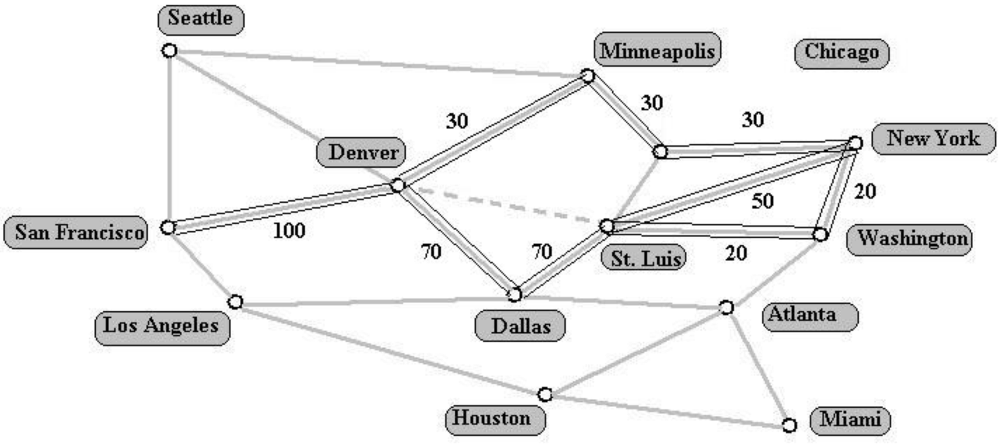
The problem of optimal allocation of traffic after catastrophic failure is considered. Matrix of traffic between various pairs of nods and capacity of trunks are taken into account. Let us assume that the traffic between San Francisco and New York iz such as presented in the figure below.



The model is working in interactive regime: a user would like to look at the network reaction on failure (or emergency turn off) of the trunk between Denver and St. Luis.



The model calculates new input data (loss of the trunk) and finds a new optimal traffic allocation between San Francisco and New York, taking into account minimum "harm" for other system users.



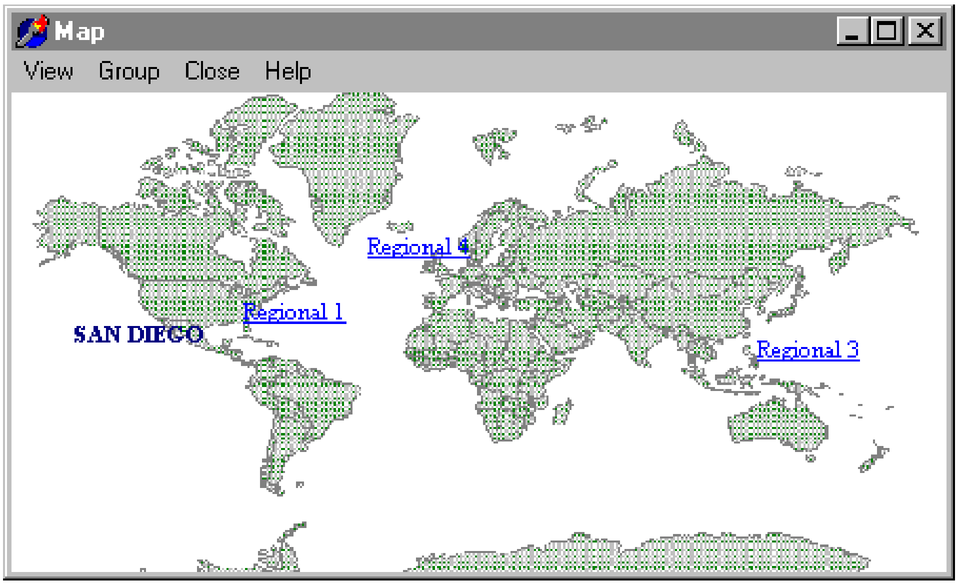
This computer model has been used for control of real telecommunication network.

Computer model for optimal allocation of spare parts for base stations of satellite telecommunication system GlobalStar

GlobalStar system uses low-orbit satellites that move around the Earth by spiral trajectories, covering practically al regions. It was planned to have about hundred ground base stations. Each such station might have its own configuration depending on the population density in the station zone, access to other communication systems, etc.

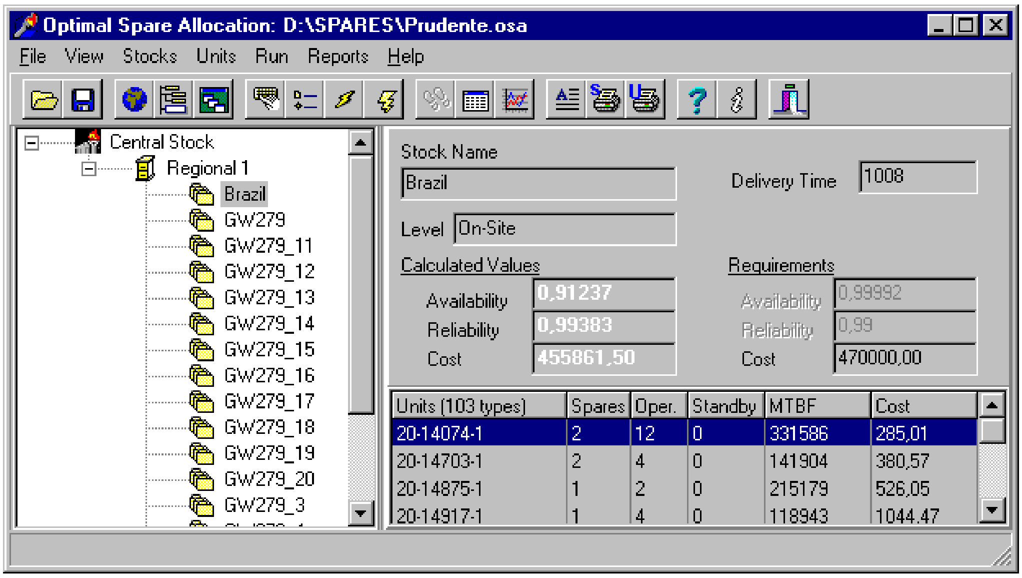
In a situation when each station might have an individual optimal allocation plan, the only possibility to solve the problem was designing of a computer model. Educated managers almost immediately understood that Neanderthal methods of type "5% of operating units, though not less than one" did not work.

It was also clear that spare supply from a single center is absolutely unreasonable. So, there were Central storage in San Diego (California) and three regional storages.

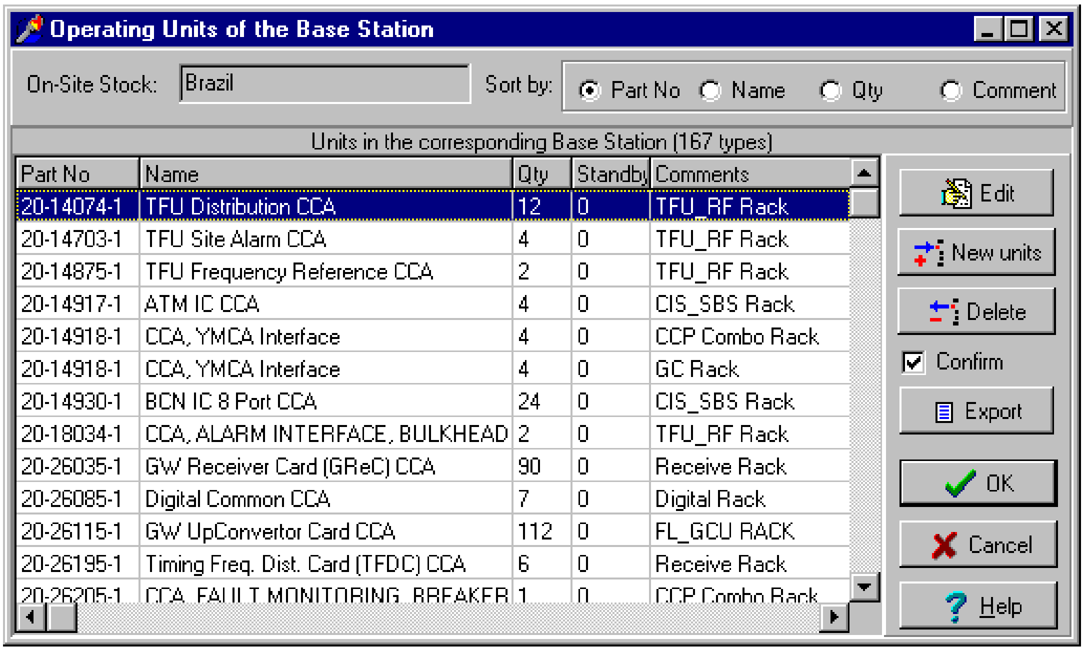


A computer model of optimal spare allocation allowed to get lists of spares for each individual base station taking into account capacity of the base station, the type of spares replenishment (periodical or by request), time of delivery and so on. Input data (failure rates of various units and its costs) were kept in a special database.

The user's window with the list of basestations within one of the regions is presented below.

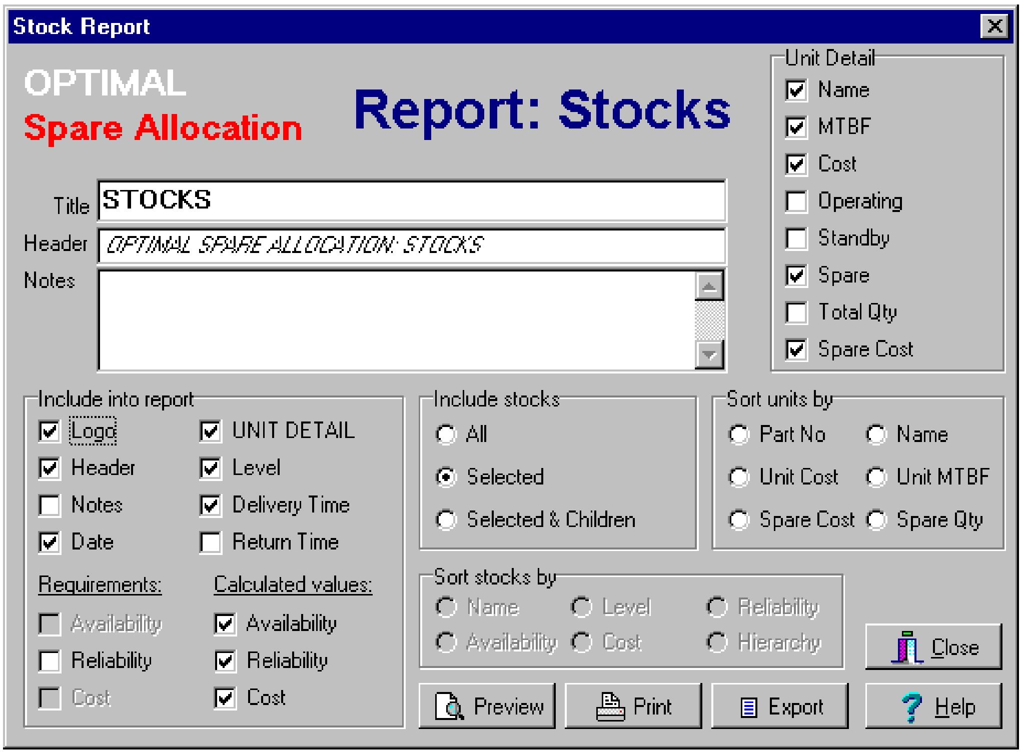


For each ground base station, the model kept all necessary input data for calculating optimal spare allocation.



Two problems can be solved: (1) Find optimal number of spare units of each type to warranty maximum base station availability under limited total expenses; and (2) Find optimal number of spare units of each type that delivered total expenses under condition that availability was not less than specified level.

After the computation, the report printing was available in the form defined by the user.



An example of the report is given below.

QUALCOMM

OPTIMAL SPARE ALLOCATION

STOCKS

Stock: Brazil *Level:* On-Site *Availability:* 0,912372575375

Spare unit delivery time: 1008 *Reliability:* 0,993832202067

Cost: 455861,50

Unit data:

Part No	Name	MTBF	Cost	Spare	Spare Cost
20-14074-1	TFU Distribution CCA	331586	285,01	2	570,02
20-14703-1	TFU Site AlarmCCA	141904	380,57	2	761,14
20-14875-1	TFU Frequency Reference CCA	215179	526,05	1	526,05
20-14917-1	ATM IC CCA	118943	1044,47	1	1044,47
20-14918-1	CCA, YMCA Interface	66667	92,42	3	277,26
20-14930-1	BCN IC 8 Port CCA	102364	609,74	3	1829,22
20-18034-1	CCA, ALARM INTERFACE, BULKHEAD	166667	178,44	1	178,44
20-26035-1	GW Receiver Card (GReC) CCA	78468	1301,53	6	7809,18
20-26085-1	Digital Common CCA	133333	788,14	2	1576,28

<u>Finding size of maintenance zones, number of servicemen and location of the maintenance center within the zone for serving users of satellite telecommunication system</u>

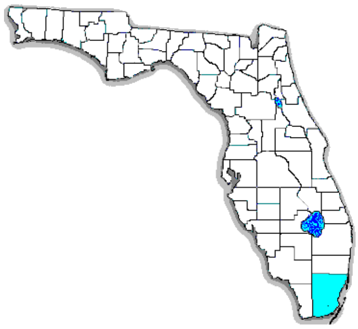
There were data of request rate obtained from a previous history of the maintenance system operation in different counties of Florida State (there are several tens of such counties)

County	Number of requests	Area	Rate (number of requests per day)
Alachua	8	902	0.148148
Baker	0	585	0
Bay	9	758	0.166667
Bradford	3	293	0.055556
Brevard	16	995	0.296296
Broward	70	1211	1.296296
. . .	. . .	. . .	. . .
Wakulla	3	601	0.055556
Walton	8	1066	0.148148

The designed computer model gave a possibility of interactive solution. Such method has been chosen because the problem had a lot of non-formalized factors. For instance, a maintenance center of the zone should be chosen at some town rather than from pure geometrical considerations.

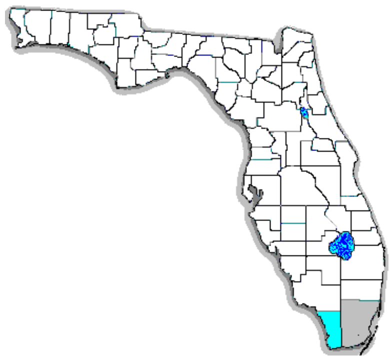
The designed algorithm based on directed enumeration with local step-by-step optimization. It was also taken into account an intuitive hypothesis that solution for, say, South Florida counties did not influence on the solution for Northern Florida counties.

The first county was chosen arbitrarily, though the maximum population density has been taken into account. Such county occurred to beDade.

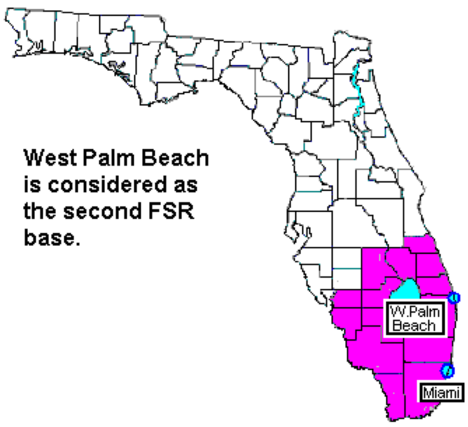


.After computing obtained maintenance parameters, it was clear that it is possible to add some neighbor county. Again informal hint for choosing the next county was that new two county should form a "compact area", i.e. this solution based on expert opinion. In this particular case the added county was

Monroe.



After multiple application of the described procedure, the first maintenance zone has been constructed.



Then in this zone one tried to split a single maintenance center into two (keeping the same total number of servicemen). It gave a possibility (again in interactive regime) to widen the maintenance zone.

After this first "macro step", the first maintenance zone became "frozen" and the same procedure is applied to find a next zone.

As the result of constructing new maintenance zones, only in Florida State alone estimated save was about $400,000 a year due to best zoning, best location of maintenance centers and decreasing the sraff.

Conclusion

Reliability Theory is alive! However, it should be applied in a right direction. Probably, needs in pure theoretical researches is decreasing, nevertheless, there are many practical problems, which are waiting solutions.

Thus, since life is continuing, the need of solving practical problems in reliability and maintainability will exist always!

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