The Founder's Lecture: The Size of a Garage

On 30th November 1999, Dr Jezdimir Knezevic, the Founder & President of the MIRCE Akademy delivered the Founder's Lecture at Woodbury Park, to around 100 colleagues from academia, industry and government.

"Dear Colleagues and Guests,

It is very well known, to most f you, that hands-on maintenance activities are very close to my heart, skills, ambitions, profession and hobby. On numerous occasions in my life I said that when "grow up", I would live in a "one-bedroom garage". When asked by numerous people what it meant, I would reply, "a garage for 6 cars with a workshop on the ground floor, with a small kitchen and a bedroom in the loft space"!

However, on the serious side (not that a one-bedroom garage was not a serious option for me), for many years I have been thinking, in philosophical terms, "who determines the size, the type and the content of the "garage", as far as the cars are concerned, dry docks for submarines, hangars for aircraft or train repair depots?" I mean, I "manufactured" my very first car, Zastava 750, at home with my own hands, with a common set of spanners, screwdrivers, pliers and other, readily available tools, which I used for all other maintenance tasks during its life with me. Very frequently I took a gearbox or an engine to my bedroom in our family flat, on the third floor of a skyscraper, much to my mother's "delight". Apart from a battery charger, I had never had or used any other special tool or equipment. During my participation in road rallying, especially those races which were a part of the European Championship, I was astonished to witness how much the "proper" rally cars, designed for competition by Lancia, Fiat, BMW, Porsche, Renault and other manufacturers had specially dedicated rally mechanics that would always arrive in specially designed and equipped vans and lorries, full of equipment and tools, power generators, wheel balancing equipment and many others, which were totally alien to me. Of course, the benefit of all of these tools and equipment was so obvious regarding the performance of cars, thanks to their ability to diagnose malfunctions and optimally set up fuel mixture, advanced ignition and other important characteristics of engines and other systems in a rally car.

However, I realised that in some occasions, when those cars developed problems on the stages, their drivers and co-drivers were totally powerless regarding any emergency repairs and actions that would enable them to reach their Support Teams, to their huge disappointments. At the same time, I found myself in that position on numerous occasions and in the majority of cases I managed to sort out the problem on my own. On those occasions, my biggest problem, by far, was the lack of adequate spares, which I neither could afford to purchase nor had the ability to carry with me due to their weight and size. Hence, since the late 1970s I, as a graduate mechanical engineer, whose job is to design mechanical systems, but also as a rally driver, whose job was to drive them in the most demanding environmental conditions towards finish lie, was thinking how the necessary balance between these two totally different jobs should be established and, even more importantly, whose job it to "care" about it.

Clearly designers are extremely busy designing the system with the best possible functionality performance, which means only one thing – maximum power for the *engine and minimum weight for the rest. It is understandable, as it is not in their nature to consider in-service diagnostics and repair issues, because users of a system are totally focused on the latter and totally removed from the former. One thing is sure: rally drivers, who drive for hours and days at maximum possible speed on the roads covered with snow, gravel, dust, sand, concrete or any other surface, are not concerned with principles and laws of thermodynamics, fluid mechanics, stress analysis and similar topics that are main concerns of the design office. Rally drivers' main concern during the whole rally, which usually lasts over 24 hours, is the part of the competing regulations, which states that the cumulative allowed delay from the scheduled times of entering and leaving time controls is 30 minute. It practically means that all diagnostics, testing, repair, replacement, adjustment and similar maintenance activities have to be completed, otherwise the cheque of flag will never be seen by the competing drivers, owing to disqualification, and yet the crossing of the finish line is the main "purpose" of their total existence."*

Dear colleagues, I am sure I've told you nothing new. However, I wish to share with you my view regarding this problem. System designers and system maintainers belong to two different professions, and their segregation starts at the age of 15-16, when those who like physics, mathematics and chemistry go to study engineering and spend their whole working career in the design office, while those who are not so enthusiastic about those subjects go to acquire different skills and trades, equally necessary for the successful operation and maintenance of technical systems. From the age of 18 both groups follow their own paths, which take them to different educational and training organisations, they usually play and follow different sports, typically they go to different pubs and restaurants, they marry different girls, they have different holidays and live in different houses at different locations. Of course, there is nothing wrong with that, but it is so clear to me that they never had an opportunity to meet, exchange experiences, concerns and worries. Please let me tell you why I think they should meet, learn about each other's concerns, limitations, frustrations and possible opportunities for working together. Between 1965 and 1969 the great Boeing Corporation, among other products, created Boeing 747, known as Jumbo Jet. In my estimates, several thousand-design engineers worked for 4 years to create an innovative, exciting and "globally life-changing" aircraft with the following measurable functionality performance:

Passengers *3-class configuration* *2-class configuration* *1-class configuration*	 *366* *452* *N/A*
Cargo*;*	*6,19 ft^3 = 30 LD-1 containers*
Engines *maximum thrust*	• *Pratt & Whitney JT9D-7A, 46,500 lb* • *Rolls-Royce RB211-524B2, 50,100 lb* • *GE CF6-45A2, 46,500 lb*
Maximum Fuel Capacity	*48,445 U.S. gal (183,380 L)*
Maximum Takeoff Weight	*735,000 lb (333,400 kg)*
Maximum Range	*6,100 statute miles (9,800 km)*

***Typical Cruise Speed** at 35,000 feet*	*Mach 0.84, 555 mph (895 km/h)*
Basic Dimensions *Wing Span* *Overall Length* *Tail Height* *Interior Cabin Width*	 *195 ft 8 in (59.6 m)* *231 ft 10.2 in (70.6 m)* *63 ft 5 in (19.3 m)* *20 ft (6.1 m)*

Table 8.1: Functionality Performance of B747

Unquestionably, the creation of B747 was a revolutionary achievement in history of the commercial aviation. However, do airlines buy an aircraft to measure the wingspan or count the number of containers that can be fitted in the cargo department? Certainly not – they purchase them to generate revenue by flying passengers and cargo to their destinations, of course "on time and never crash". I was fortunate enough to have access to the logbook of the very first Boeing 747 owned by Pan Am, registration number N747PA, which, during the 22 years in-service, has recorded the following data:

Positive Action	***Unit***	***Quantity***
Airborne	*Flying hours*	*80,000*
Flown	*Miles*	*37,000,000*
Transported	*Passengers*	*4,000,000*
Take offs	*n/a*	*40,000*
Landings	*n/a*	*40,000*
Fuel consumed	*Gallons*	*271,000,000*

Table 8.2 Functionability Performances

The above information is purely related to the revenue and cost of the business, which are of prime importance for Pan Am airline, However, I wish to share with you the following, maintenance-related data:

Maintenance Actions	***Quantity***
Number of tyres replaced	*2,100*
Number of brake systems replaced	*350*
Number of Engines replaced	*125*
Number of times passenger compartment replaced	*4*
Number of times passenger compartment replaced	*4*
Number of X-ray frames of film used for structural inspections for metal fatigue and corrosion	*9,800*
Number of times the metal skin on its superstructure, wings and belly replaced	*5*

Table 8.3 Maintenance Activities performed on N747PA

It is my great pleasure to inform you that all maintenance-related actions on this aircraft amounted to 806,000 maintenance man-hours. To make it more *comprehensible, it is around 36,636 maintenance man-hours per each year in-service, or 3053 hours per each month in-service or 102 hours per each week in-service or 4.24 maintenance man-hours per each day of existence! I am sure that these numbers are so convincing that from now on, each of you will be asking the same question and will join the MIRCE Akademy in the development of the science-based knowledge for normalising the designing for functionality performance and designing for functionability performance. Although, majority of B747 design engineers have died by now, the majority of their aircraft produced are still in the hands of maintainers, on a daily basis, in almost every country in the world.*

Please raise a hand, each of you who have ever flown or know anybody who has flown in a Concorde. A typical response to this demand is none or one. My typical reply is "the reason for this is the fact that none of you are mixing with royalties or drug dealers, as they are the only people who can afford the price of the ticket." At the same time, majority of us have flown in a B747. Let me tell you that the only reason for that is maintenance. From the data presented earlier you could have seen that B747 requires, on average, 10 maintenance man-hours per flying hour, whereas that number for Concorde is 137!

For years and years I was aware of these facts and as an individual I mixed with both professions: starting with my summer practice in the Skoda garage in Belgrade at the age of 15 where I made a few friends among car mechanics, with whom I am still in contact and have a great pleasure spending time with, as well as being a colleague and friend of the top designers of the world leading defence and aerospace companies, today. Despite my own efforts to mix with both professions, I am fully aware that car mechanics, or any other types of mechanics, are not employed in the design office of any company in the world. In a very similar way, the great Jack Hessburg, the Chief Mechanic of Boeing New Airplanes, was fully aware that gate mechanics are not present at the design review meeting of their future airplanes. Although Jack and I are 20 years apart, age wise, we came to the same conclusion. This is not a generational phenomenon; it is a professional phenomenon, which passes from generation to generation. Thus the long-term professional challenge is to figure out how to bring in-service practicality and reality of mechanics into design office. This challenge brought us together at the beginning of the 1990s. Jack knew that the work of gate mechanics is determined in the design office, while I knew that car designers determine the size of the garage, certainly not by car mechanics or rally drivers.

Thanks to the visionary top managers of the Boeing Company, Jack was given an opportunity to bring gate mechanics into the design office, and he rose to the challenge, as the World's first Chief Mechanic during the design of B777, paying great attention to their views on the proposed design solutions. It was an extremely successful collaboration under Jack's leadership. However, during that process Jack also realised that, as a designer, he had to decide where to put economic redundancy on behalf of his customer, and that whatever he did would cost money to both of them. Jack's challenge, on behalf of the Boeing Corporation, was to determine the combination between minimum equipment list the degree of reliability and economic redundancy that would minimise the probability of an aircraft being in the position where it is not able to fly because of the intrusion of airworthiness. Unquestionably, Jack was fully aware that a right balance had to be found, as customer is paying extra *for these things by carrying them for the next 20-25 years, and Boeing is paying for their installation in the first instance. Well, the necessity for determination of the methodology for finding the correct balance between these three competing dimensions, from the point of view of "going on time and never crash" witch was clearly identified and eloquently presented by Jack during his Lecture for the M.I.R.C.E. Centre postgraduate students and Members of Industrial Club at the Exeter University in January 1998 and also a few months ago, when he officially opened the Akademy.*

Of course I fully understood Jack's challenge, as during my short but intensive rallying career I had faced the same challenges, though not with cost of economic redundancy, but with the weight of "reliability" redundancy, as the 750 cm^3, 23 KW engine of my car, could not have carried many spare parts and corresponding tools and equipment, while still being competitive, especially during the speed trials up hills.

The fundamental question for all of us, Jack and myself in this particular instance, was: "Is this a trial-and-error type of exercise or is it possible to develop a science-based methodology that would unambiguously provide an accurate and quantitative answer to designers at the design stages when alternative courses of action could be examined before making commitments with which both sides would have to live "happily" for decades to come?" I am sure it will not come as a surprise to you if I tell you that I firmly believe in the latter option, and the quest for that body of knowledge has brought me here, from the Exeter University, and this Lecture tonight is the "official" beginning of that necessary but challenging process.

Ladies and gentlemen, it is my great pleasure to inform you tonight that, in consultation with numerous colleagues and students, we have decided that the name System Operational Science will be used at the MIRCE Akademy as "a scientific body of knowledge" that we are seeking to develop. Thus, I wish to launch the concept of the new discipline that we defined as follows:
"System Operational Science studies the behaviour of functional systems through in-service life, to understand processes, factors and environments that shape their functionability performance and generates the knowledge necessary for their systematic prediction."

Please be gentle with us, during the next few years, as this is our very first attempt to formulate a coherent body of knowledge that integrates all the known "-ilities" with other system engineering disciplines that are already recognised and very successful in designing functionality performance of systems, and yet are unable to even address the process of prediction of their future functionability performance.

To deliver functionality in the time domain, all functional systems must engage in an operational process that consists of a flow of operation, maintenance and support tasks. Successful execution of these operational tasks, in time and space, is connected with a necessary type and quantity of resources like personnel, equipment, facilities, tools, data, energy and material. Operational experience teaches us that irrespective of how good a system may be, interruptions in the provision of the functionality will occur during its life, caused by:

- *Inherent deficiencies of materials, design and production processes*
- *Irreversible processes that take place in the system itself*
- *Interaction of the system with its operational environment*
- *Planned execution of operational and maintenance tasks*
- *Insufficient operational and maintenance resources*

Based on my experience, the flow of the functionality through the in-service life of functional systems is not a deterministic process and cannot be treated with the same degree of certainty as their performance, weight and other physical characteristics. To deal with variability, inherent in the system itself and in its operational interactions with natural, human and business environments, System Operational Science draws on the concept of probability. The role of probability is to facilitate the prediction, as it is impossible to know exactly what sequence of in-service events a given functional system will have during its operational life.

Our ultimate goal is the creation of advanced methods, techniques and tools that would enable engineers and managers to quantitatively assess and predict the functionability performance of systems in time, at a stage when the best alternative can be identified at the lowest cost, time and risk".