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Use of Technology in Scuba Diving

Dive Computers: Ensuring Continuous Safety and Peak Experience

Amar Djozic

Dissertation

presented as partial requirement for obtaining the Master Degree Program in Information Management

NOVA Information Management School
Instituto Superior de Estatística e Gestão de Informação
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USE OF TECHNOLOGY IN SCUBA DIVING

DIVE COMPUTERS: ENSURING CONTINUOUS SAFETY AND PEAK EXPERIENCE

By

Amar Djozic

Master Thesis presented as partial requirement for obtaining the Master's degree in Information Management, with a specialization in Information Systems and Technologies Management.

Supervisor: Vitor Manuel Pereira Duarte dos Santos, PhD

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration. I further declare that I have fully acknowledge the Rules of Conduct and Code of Honor from the NOVA Information Management School.

Amar Djozic

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Greatest thanks and all praise are due to God Almighty, the most Gracious and the most Merciful, who is the ultimate provider of beneficial knowledge. Hereby, I supplicate to Him that the gained knowledge is used and shared in His name, so the society benefits from it. Verily, to Him we belong and to Him we shall return.

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ABSTRACT

This paper deals with underwater diving. From using a tortoise shell as a diving mask to using cutting edge high-tech, people have been stipulated to use technology in order to spend time underwater. Certainly, without technology, we wouldn't be able to go as deep and long as we are going today. But, even with technology, there are limitations and risks. This paper deals with the use of technology in scuba diving. More precisely, the technology of a dive computer will be elaborated. Dive computer is a battery powered, pressure-resistant device which provides real-time information on depth, elapsed time, temperature, etc., but most importantly it assists divers in attaining low or no risk of decompression sickness by using decompression algorithms. The ultimate goal of this paper is to build a comprehensive framework for the use of technology in scuba diving. In order to achieve mentioned, it is necessary to manifest the utility and essence of technology in scuba diving. This partial requirement is concerned with introduction in the topic, methodology chosen for the research, review of literature used, framework development and proposal, and conclusive words.

KEYWORDS

Scuba diving; diving technology; dive computer; dive safety

INDEX

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

AIS – Automated identification system

BM – Bubble model

CMAS – Confederation Mondiale des Activites Subaquatiques

DAN – Divers Alert Network

DCS – Decompression sickness

DEMA – The Diving Equipment & Marketing Association

DGM – Dissolved gas model

DSR – Design Science Research

ERDI – Emergency Response Diving International

GPS – Global positioning system

IS – Information system

NAUI – The National Association of Underwater Instructors

PADI – The Professional Association of Diving Instructors

PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RDP – Recreational Dive Planner

RGBM – Reduced gradient bubble model

SCUBA – Self-contained underwater breathing apparatus

SDI – Scuba Diving International

SIT – Surface interval time

SSI – Scuba Schools International

TDI – Technical Diving International

1. INTRODUCTION

1.1. CONTEXT

Technology has been improving our daily lives, but has it contributed to mitigating hazard such as underwater? People, by default, are residing on land and dry surfaces. Our fascination with the underwater world goes back to the beginning of a currently recorded history. Only because of technology, we have managed to go deeper underwater. Humans have felt a deep desire to explore unknown, and the oceans are a vast of largely unknown part of our planet. The origins of diving are firmly rooted in humans' need to engage in maritime commerce, to conduct salvage and military operations, and to expand the frontiers of knowledge through exploration, research and development (US Navy, 2016). Ancient technology, such as hollow reeds used as a snorkels or tortoise shells used as a first googles, has come to the complex technology which provides comprehensive life support to deep divers, enabling them to explore and exploit deep waters (Parr, 2018). Subsequently, a development of dive computers has emerged. Dive computers serve as an underwater, battery-powered, waterproof and pressure-resistant devices which allow divers to keep track of their elapsed time, depth and gas mixtures during the dive. Dive computers will provide instructions on safe bottom times and ascent schedules based on real-time information. These devices have assisted massively to improving performance, safety and experience of scuba divers. But there are still risks and dangers when it comes to spending time deep underwater, especially in the case of presenting the sport to a non-diving community.

Then, why is scuba diving so attractively hazardous? Simply, mankind by default is not able to breathe underwater. A person is very poorly equipped physiologically as a diving being and there is a myriad of problems associated with breathing gas under pressure (Starck, 1972). Why is it attractive? Because oceans are a vast part of the Earth which is still greatly unattainable to us. But, throughout the history, development of a technology has allowed us to extend a research and discovery of those mysterious undersea world. This development happened solely because of development of scuba equipment. Fundamentally, SCUBA is an acronym, which stands for self-contained underwater breathing apparatus. Many variations had been invented, but it was not until 1943 when Jacques Cousteau, an underwater diving pioneer, invented the demand regulator. The demand regulator enabled a diver to breathe air at the proper pressure for his depth and in the amount that he needed (SSI, 2021). After many unsuccessful attempts, for the first time a diver could descend into the undersea world with a complete, independent life support system, self-contained and free. This innovation, along with high-pressure compressors and cylinders, gave birth to SCUBA.

After millennia of working underwater with constraints of a single breath or heavy hoses and lines, man could finally enter the ocean untethered. The foundation was set for the exciting sport and science of scuba diving and the world renewed its romance with the ever mysterious, but now more accessible sea.

Angelini (2011) classified diving into five categories:

- Recreational – dives shallower than 40-50 meters, within the no-decompression limits, primarily using the same breathing mix from beginning to end

- Technical – dives pushing depths beyond 100 meters and/or dive times to 20 and more hours, using highly dedicated equipment and multitude of breathing mixes tailored for each part of the dive

- Scientific – dives for scientific purposes shallower than 60 meters usually within the no-decompression limits, breathing air or N2O2

- Commercial – dives with specific goals such as maintenance and/or inspection of underwater facilities

- Military purposes diving

Therefore, scuba diving as we know it today is relatively young sport. The major technological breakthroughs and instructions occurred over the past 25 years. The industry of scuba diving has advanced significantly since the introduction in mid-twentieth century of the first SCUBA and today offers great technological equipment for people to explore deeper, longer and in environments not considered possible earlier (Jacobsson, Evaldsson, 2017). During the mid-19th century, scuba systems appeared on the market, but diving instructionals were non-existent. That period of scuba diving could be considered as a "wild west" era. Sheer strength and determination of a very fit individuals were the substitutes for scuba systems' lack of safety. The lack of air pressure gauge was the most significant hazard to divers. When the air supply was depleted, divers were forced to ascend rapidly to the surface. Additionally, air supplies were massively resistant because of the pressure increases proportionally with depth increases, where the gas volumes would impulsively decrease. Accordingly, overexpansion and decompression injuries can appear. Luckily, this perspective has been changed. Diving professionals realised that everyone, in the underwater environment, are dependent on their training and equipment.

We mentioned some of the possible adverse events of injuries. One of the major ones is called decompression sickness. Decompression sickness is a disorder in which nitrogen dissolved in the blood and tissues by high pressure forms bubbles as pressure decreases (Moon, 2021). It develops due to inert gas bubble formation in bodily tissues and in the circulation, leading to a wide range of potentially serious clinical manifestations (Magri, Eftedal, Pace, 2021). Around 70%-75% of human body is formed from liquids, and they are not affected by pressure changes. The problem lies in the remaining which is consisted out of gases. Gases are verily affected by rapid pressure changes. Sickness can manifest itself as a consequence of lowering the barometric pressure after a compressed gas dive and during air travelling situations, where its effects are often very severe and self-limiting (Pinkowska et al. 2020). Therefore, the pressure and the corresponding changes must be maintained in a suitable manner. As an example, at the atmospheric pressure of 1 bar (surface/land pressure), the usual gas mixture that we breath (air) is composed of a partial pressures of nitrogen (0.79 bar) and oxygen (0.21 bar). At the depth of 10 meters (absolute pressure is equal to 2 bars – every 10 meters absolute pressure increases for 1 bar), the gas mixture that we breath is composed of a partial pressures of nitrogen (1.58 bar) and oxygen (0.42 bar). As exemplified, partial pressure doubled with the increase of an absolute pressure. Therefore, a gradient (pressure difference) between the nitrogen in our blood and nitrogen in our lungs is 0.79 bar! The process of desaturation begins as a diver commences his/her ascent back to the surface. Nitrogen remains in solution in tissue fluids and the bloodstream as long as the external gradient does not become too high. The human body can stand a certain level of supersaturation. However, if the pressure difference becomes too large, the nitrogen will come out of solution in the form of free gas bubbles in the tissues and bloodstream, resulting in various forms of tissue damage (Healthwise, 2020). In conclusion, a diver returning from depth to the surface may be supersaturated with nitrogen. It may happen if a diver stays too long at the certain depth or if he/she surfaces too quickly. Observing the depths, remaining times, remaining gases, controlled ascents and performing safety stops are simple prevention methods.

Decompression planning was originally based on printed decompression tables developed by John Scott Haldane, essentially to facilitate assistance to deep divers (US Navy, 2016). Using these tables were inefficient for multi-level diving and a lot of discrepancies between theoretical model and experimental practices. From pneumatic analogue to electrical analogue computers, nowadays we have digital dive computers assisted by artificial intelligence. Early on, microprocessors in computers were encoded with decompression tables, but now most computers are encoded with a decompression algorithm – a set of mathematical equations designed to simulate the uptake and release of inert gases within a diver's body (Lippmann, Wellard, 2004). Dive computers are primarily used to monitor and calculate decompression schedules and have the advantage over conventional tables because they compute decompressions for multi-level dives and in real time (Angelini, 2012). They have been applied to studies such as marine biology, reef measurement, pathology, decompression modelling, georeferencing, dive accident investigation, physiology, physics, etc. All these studies rely on a relatively accurate data conversed from measured pressure to displayed depth.

From dive tables in 1908, over pneumatic and analogue, up to the modern high-tech dive computers, we have come across long way. Below, we can see the brief timeline of diving evolution (Egstrom, 2006):

- 332BC - Aristotle described the diving bell that Alexander the Great was to have used for underwater observations in the Mediterranean. Reports that he was using underwater swimmers for military purposes also seem credible.

- 1500's: Da Vinci recorded evidence that the study of underwater life support was moving forward and presented a conceptual scuba apparatus.

- 1535: Lorena developed a true diving bell.

- 1650: Von Gierke was credited with the first effective air pump.

- 1691: Halley's Bell with primitive air supply system.

- 1715: Lethbridge's Diving Engine, 30 minutes at 18m.

- 1774: Freminet performed surface-supplied dives at 15m.

- 1837: Siebe connected the helmet to diving suit.

- 1850: Green used diving armor in Lake Erie for salvage between 4-21 meters. Green dived 48m on Silver Banks, many dives were reported over 42m.

- 1865: Rouquayrol-Denayrouse Aerophore permitted diver to disconnect surface-supplied air and move about freely for a short time using a reservoir of compressed air; 45m limitation.

- 1876: Fleuss developed a self-contained compressed O2 unit.

- 1882: U.S. Navy Diving School, Newport, Rhode Island.

- 1893: Bouton made first underwater photographs.

- 1904: British working dives to 210 ft.

- 1905: Manual for Divers, U.S. Navy Diving School trained to 200 ft.

- 1906: Haldane diving tables, 62m on air.

- 1908: Haldane reported on the prevention of compressed-air illness.

- 1920: Le Prieur developed self-contained apparatus. U.S. Navy researched heliox for deep dives.

- 1925: Diving experiments Helium/Oxygen 80/20 .

- 1927: U.S. Navy Experimental Diving Unit developed HeO2 capabilities.

- 1933: Corlieu patent for swim fins. Le Prieur used 1500 psi air with manual valve and no regulator.

- 1935: Behnke studied O2 toxicity effects at PO2 of 1-4 ata. Determined that bottom time, depth, and highly variable individual response were critical.

- 1939: U.S.S. Squalus dives used air and heliox to 74m, recovered submarine.

- 1942: Cousteau/Gagnan redesigned a pressure regulator for use underwater.

- 1945: Zetterstrom reached 161m on hydrogen/oxygen but died from an acute lack of oxygen on ascent, unable to change over his gas supply from the deep mix.

- 1946: The Aqualung was commercially marketed.

- 1948: 10 Aqualung units became available at Rene's Sporting Goods in Westwood California. Post in NYC and Pederson in Chicago were also selling Aqualungs.

- 1951: First official diving course at UCLA, Scripps Institution campus. Skin Diver Magazine began publication.

- 1958: U.S. Navy published Dive Tables for air down to 90m.

- 1968: Gruener and Watson dived to 133m on air. U.S. Navy saturation to 251m with excursions to 312m.

- 1976: OSHA enacted rulemaking covering commercial diving operations. AAUS formed to provide representation for scientific diving. U.S. Navy light-weight mixed-gas diving gear used for 91m dives on heliox with Superlite 17 and Kirby-Morgan Band Mask.

- 1999: British depth record holder Andrews dived on air to 156m. S. Watts dived to 130m on air in Cozumel.

- 2003: Ellyat open-circuit dived to 313m.

- 2005: Gomes open-circuit dived to 318m.

- 2006: 1,160,000 hits on the internet for "scuba dives 100 meters ". "Scientific divers and deep diving" had 2,180,000 hits. "Scientific deep diving human" had 1,850,000 hits.

- 2014: Ahmed Gabr breaks world record for the deepest dive – 332.25 m

1.2. Motivation

Deep diving is primarily supposed to be fun. During the amusement, we need to take into consideration the purposes of diving (scientific research, commercial, leisure, etc.), furthermore securing the continuous safety while mitigating all the risks and dangers for people's health and experience, and preserving the environmental wellness. Scuba diving is an important and growing component of the international tourism market, and is heavily reliant upon natural marine areas (Davis, Tisdell, 1995).

Therefore, using a technology to gather all the essential information and practices from the past and to create new policies in order to provide top safety and peak quality should be an ultimate goal of a scuba diving industry. In regards of that matter, relying on scientific based information and utilities of information technology must be pursued to design a framework which will furthermore provide a comprehensive system of peak performance, safety and experience.

Diving computers are a vital part of each diver's equipment, alerting the user all the crucial information (Jacobsson, Evaldsson, 2017).

As already mentioned, decompression tables have been a decent source of tracking and monitoring dive conditions and factors, but dive computer have enabled divers to explore and exploit so much more. But still, that does not mean that risks and danger of decompression sickness has changed. Rather, divers should practice enhancing the utility of mentioned computers and ensuring that dive computers are free and safe from any environmental hazards and/or human errors. When it comes to human errors, through theoretical research and user practices/experiences, the aim is to define several elimination methods. If error elimination is not viable, then at least a mitigation methods should be possible and applied. After surfacing the computer, we must ensure that all the extracted data is authentic and valid for the research of future diving. Additionally, with the combination of above mentioned methods, there will be a methodology ensuring the elimination of gear malfunction or hardware error.

Acceptable measures vary depending on the category of diving. Those measures should have a decompression sickness probability close to zero. Built on the Haldane's framework of decompression models, we will take a look on several algorithms which serve as a mathematical models used to calculate safe dive profile and limits.

It is important to understand that a computer's algorithm is entirely arbitrary, meaning that it cannot measure the actual physical processes that are taking place in our body when diving (Roy, 2014). Computers do not know whether we had enough sleep or not, whether we are hydrated enough, etc. The risk of decompression sickness also depends on an individual's physiology, fitness and health conditions. Therefore, we must verify that computer functions correctly, and that all the data is valid afterwards. This leads to the interrogations and to the formulation of the following research question:

How can we ensure continuous safety and peak experience in scuba diving?

The motivation behind this question lies in adverse events that happened throughout the history of diving. There were one too many fatalities due to the lack of holistic and systematic approach on how to use technology while diving.

1.3. Objectives

The ultimate research goal is to create a framework for the use of technology on the continuous safety and top quality for scuba diving.

Additionally, it will be proposed instructional and educational guidelines in order to ensure continuous safety and top quality.

To achieve previously mentioned, the intermediate objectives have been defined:

- Manifest the utility and essence of technology in scuba diving

- Build a comprehensive framework for the use of technology in scuba diving

- Update instructional and educational guidelines for scuba diving practices

- Propose recommendations for improving dive computers

Some intermediate questions that should be answered during the development of this paper are:

- How can we ensure that algorithms running in a dive computer are not affected by environmental hazards?

- How can we ensure that extracted data is accurate and valid for the future research?

- How can we eliminate gear malfunction or software/hardware error?

- How can we mitigate human error?

1.4. Study Relevance and Importance

The combined worldwide sales of dive computers from all computers does not exceed 500,000 units per year, so it becomes obvious that dive computers do not drive new technologies, but rather benefit from a trickle-down effect (Lang, Angelini, 2009). Therefore, a motivational factor can be the introducing of embedded technologies. The age of electronic diving has arrived with the development of the modern electronic dive computers as the most significant advancement in self-contained diving since the invention of SCUBA. Almost half a century later after the introducing of electronic dive computers, several key questions remain surrounding the decompression models used, validation and human testing, acceptable risk, limitations, failures and operational reliability.

Many decompression algorithm models have been developed. Some of the most notable are Buhlmann’s, RGBM, VPM, DSAT, but there are also many models developed by computers’ manufacturers. Probably, there is not a definitive answer to which algorithm is better. The complex nature of human physiology entails that a certain amount of conservatism is essential (DND, 2021). The development of dive computers in modern times will have to link with concomitant advances in general microprocessor development (Azzopardi, Sayer, 2010). It is possible that this evolution will produce unwelcome outcomes associated with misunderstanding on how the computers work (Sayer, 2008).

The validation of computer's data is crucially important. Again, a certain degree of conservatism is essential. Currently, many questions cannot be answered because of the lack of data and data discrepancy. Lang and Angelini (2009) question the validation of running algorithms while asking who should be in charge of evaluating the operation and validation of dive computers.

As the general advancements in consumer electronics industry are proceeding, dive computers have not been skipped and many innovations have been introduced. Certainly, huge opportunities lie in terms of improving divers' safety and experience with the help of dive computers. Better display, longer battery lives, GSP and similar signal technology, underwater communication and navigation, hearth rate monitoring, body temperature, gas saturations, etc. should be considered, researched and assessed.

It is apparent that the diving culture differs from those of other extreme sports. The diving industry is driven by technical, technological and performance-oriented products and services. The nature of scuba diving is characterized by safety and thus technology is developed thereafter. Ultimately, this is something positive, however for most recreational divers the primary driving force is not the performance but rather the experience of diving (Jacobsson, Evaldsson, 2017). Surely, there is a major potential in developing products that are meant to highlight and improve the experience more, while still respecting all the necessary safety guidelines (or even improving them as well).

Marine tourism has been the focus of tourist attention and countries with valuable coral reefs attract millions of scuba divers (Higham, Luck, 2008). This type of tourism is probably the main source of income for the scuba diving shops, instructors and other professionals. Motivations to travel specifically for scuba diving are many, such as adventure, challenge, excitement, relaxation, etc. Professional Association of Diving Instructors (PADI, 2019) stated that they issued over 27 million diving certifications since 1967, and there are four or five more notable world associations in charge of scuba diving certification. The contribution of scuba diving to the marine tourism environment is significant and considered one of the world's fastest growing recreational sports, developing globally into a multibillion dollar industry (Ong, Musa, 2012).

2. METHODOLOGY

Main, but not restricted to, methodology used in this paper is the design science research methodology. This methodology is consisted out of six guidelines and it is mainly used for information systems research. Within this setting, the design science research paradigm is proactive with respect to technology. It takes a simplistic view of context in which participants must function.

Moreover, the methodology designed by Peffers et al. (2006) is comprised of:

1. Problem identification and motivation – Specific research problem and solution value definition

2. Objective for a solution – Blueprint of solution and testing of artefact's utility, quality and efficacy

3. Design and development – Developing of solutions to relevant problems and determining artefact's desired functionality

4. Demonstration – Clear contributions of artefacts and foundations

5. Evaluation – Observation, evaluation and viability of methods application

6. Communication – Discussion of artefact's utility, novelty, rigor; Presentation of reviewed content to an audience

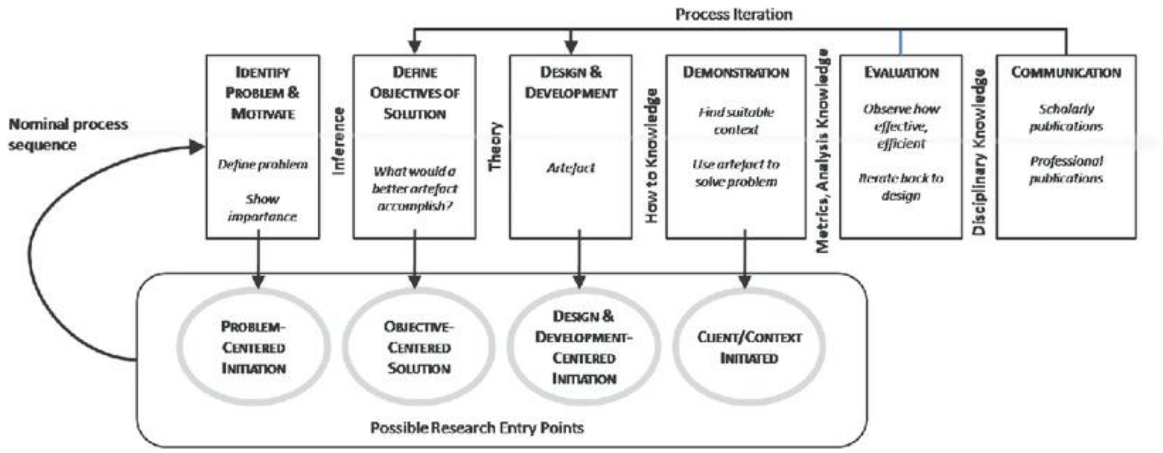

Figure 1 - Design Science Research (Peffers, 2006)

The goal is to make this paper simple to a degree that the content presented will justifiably be understandable to readers from non-diving community. The general assumption has been that potential audience does not have prior knowledge of this industry. So, apart from the goal of enhancing current practices in scuba diving and possibly innovating new ones, additional goal is to bring this industry closer to general audience. Furthermore, parameters and intermediate methods may not be as simplest as possible, but the final framework should be perfectly clear and applicable universally without any constraints. Ultimately, readers should have the same understanding of the topic as the researchers.

If possible, there will be practical experiments included. However, conducting experiments underwater requires a lot of planning and resources so it might not be feasible to implement them in this work.

It should be noted that scuba diving, regardless of its nature, is relatively young sport and it is not massively scientifically explored. Lack of scientific papers will be substituted by extensive research from the author and results/findings from experimental attempts.

Sciences of medicine, physiology, physics and biology will be exploited in order to prove connection between the perks of technology and the final framework – ensuring continuous safety and top experience.

2.1. Design Science Research Methodology (DSR)

Design science is of importance in a discipline oriented to the creation of the successful artefacts (Peffers et al. 2008). It entails all the principles and procedures necessary to carry out the research and it needs to satisfy multiple criteria.

Information systems (IS) is an "applied" research discipline, we acknowledge, it is essential that we apply theory, frequently from different areas, to solve problems at the intersection of IT, organizations and other participants. Yet the dominant research paradigms we use to produce and publish research for our most respected research outlets largely continue to be traditional descriptive research borrowed from the social and natural sciences (Peffers et al. 2006).

Improvement of artefact design knowledge is one of the essential components of systems design research (Peffers et al. 2006). IS design that applies contemporary methodologies can provide new knowledge that could improve particular artefact designs (Miah, Genemo, 2016). The goal of using DSR is to reinforce and explore the current and previous status in literature, then to try and apply it in practical and feasible context. Certain qualitative and quantitative criteria have been implemented, which will be discussed later in this paper. By conducting the research, the process should be designed which will support work development via: being consistent with design science processes in other disciplines, providing a nominal process for conducting the research, and providing a mental model for what design science research output should look like.

In essence and ultimately, design science research creates and evaluates IT artefacts intended to solve identified organizational and process problems (Peffers et al. 2008).

Objectives for a design science research process model	Archer (1984)	Takeda (1990)	Eekels, Roozenburg (1991)	Nunamaker (1991)	Walls (1992)	Rossi (2003)	Hevner (2004)
Problem Identification and Motivation	Programming Data collection	Problem enumeration	Analysis	Construct a conceptual framework	Meta-requirements Kernel theories	Identify a need	Important and relevant problems
Objectives of a Solution			Requirements		Design method Meta design		Implicit relevance
Design and Development	Analysis Synthesis Development	Suggestion development	Synthesis Tentative design	Develop a system architecture Analyze and design the system Build the system		Build	Iterative search process Artefact
Demonstration			Simulation Conditional prediction	Experiment Observe Evaluate			
Evaluation		Confirmatory evaluation	Evaluation Decision Definite design		Evaluate	Evaluate	Evaluate
Communication	Communication						Communication

Table 1 – Design and design science research process elements from IS other disciplines and synthesis objectives for a design science research process in IS (Peffers et al. 2008)

2.2. Steps in DSR

2.2.1. Problem Identification and Motivation

It is important to understand that a computer’s algorithm depends entirely arbitrary use of its owner, meaning that it cannot measure the actual physical processes that are taking place in our body when diving (Roy, 2014). All diver training associations still regard it important that divers learn in any way why and how our body tissues are being enriched by gases which constitute the gas mixture divers breathe underwater; and it is also still regarded essential for divers to get to know and manage the tools that are designed to avoid problems from this absorption of gases which always takes place in us when we use scuba to seek adventure and recreation in our fascinating underwater realm (Wild, 2014). But, still problems happen on an ongoing basis.

From dive tables in 1908, over pneumatic and analogue, up to the modern high-tech dive computers, we have come across long way. Data from the Europe Diving Safety Laboratory suggest that approximately 95% of recreational diving is carried out today using a dive computer (Balestra, 2012). The research should answer the question on whether divers rely on computers too much or they don’t use it properly and up to sufficient extent. Dive computer by itself does not guarantee safe and amusing dive. Rather, it just monitors a tiny fraction of the underwater situation. A diver must remain cautious and aware continuously in order to eliminate the risk of incidents and to enjoy the dive.

Answering the question ‘are we too reliant on dive computers?’, Pienaar (2020) states that even though dive computers are ubiquitous in the scuba community, responsible divers should still understand the theory behind the calculations computers make. Again, that brings us to the conclusion that divers cannot just strap on the computer and start diving. As it is mentioned, scuba diving as a discipline is comprised out of various scientific and other areas; thus knowledge and skillset out of those is necessary in order to conduct safe and fun diving.

According to the Divers Alert Network (DAN, 2019), out of 169 deaths related to recreational diving (which is 33% higher than year before):

- 10% had received advice that they were medically unfit to dive
- 10% were not trained properly to dive when they dived
- 25% experienced difficulties at the surface before dive
- 86% were alone when they died

DAN (2019) also states that diving fatality occurs in 1 out of 211,863 dives. Therefore, scuba diving shall not be perceived as somewhat dangerous and risky activity. When rules and policies are respected, scuba diving should be considered as a safe sport. A responsible diver who seeks training and dives within his/her limits, results in risks of diving are even lower (Gibb, 2019).

Thus, both conservatism and liberalism in validating dive computer’s algorithms and computer’s data are not to be relied on. Dive computer algorithms are based on theoretical models, which means they are not adapted and personalized to a diver that uses mentioned computer. On the other hand, any dive computer that is available on the market is safe to use if you follow its limits and guidance. Divers end up in trouble not because of dive computer, but because of mistreating, misinterpreting and ignoring it.

2.2.1. Objective for a Solution

After we summed up the issues in area of diving and the corresponding technology used, the conclusion is that trouble is not caused by the technology, but rather by people who use it. Therefore, that is the ultimate reason why the mentioned framework is essential in order to create an environment for peak experience and continuous safety.

Framework would represent the set of rules and policies which are supposed to tackle the problems in suitable manner. Dive computers that calculate and display decompression information have been evolving in their accuracy, complexity and the range of information being manipulated, which means that these technological advances have increased computer’s capability to provide high-quality information for a diversity of uses (Sayer et al. 2008). However, information provided has been opened to misinterpretation.

Therefore, the first and most important criteria would be to suitably understand and interpret decompression data and information related to it. As mentioned, computer by itself cannot facilitate safe decompression, but it can and will provide diver with information on suitable gas mixture, pressure levels, exposure history, ascent/descend speed, depth, etc. The clear understanding of that data and summary of it should be sufficient to bring risk of decompression sickness to a minimum.

2.2.2. Design and Development

After gathering all the necessary requirements, both technical and declarative, for design and validation of the framework, we need to provide a relevant instructive information on how to use and implement the framework properly and safely.

Hamilton (2011) proposes that there are four steps in validating a dive computer. First of them is ergonomics, in which the summarized essence is the interface of computer with the diver. A diver should possess certain level of manipulation power over computer, but it should also be limited in order not to mistreat its work or data provided. The controlling of a computer should be intuitive and it should not require a particular training in order to handle it. Comfort and fit are also important and taken into account. Safety requirements are top of the priority, where certain details are essential for computer's validation (no water penetration, dry battery compartment, etc.).

While we will not create, change, or manipulate a dive computer's algorithm, it is the business end of a computer and it is the most important tool to calculate dive profile. However, testing of a computer and its corresponding algorithm is essential and will be conducted. The best solution for this is to conduct simulation dives, which is a prerequisite process for computers' manufacturers and hyperbaric scientists. But when it comes to actual practice and field testing, framework should have greater level of security regarding information provided. The point being that in order to adequately test a dive computer, its evaluation needs to be done using a variety of different people of all sizes, shapes, ages, weights and skill levels (Hamilton, 2011).

Because few human subject studies have been performed to validate dive computer decompression algorithms, there needs to be a method to evaluate the associated decompression risk for commercial diving use (Huggins, 2011). Therefore, Huggins (2011) proposed a protocol for assessing the risk of dive computer algorithms, which is comprised of six steps:

1. Select profiles that have been tested and have known outcomes similar to previous dives
2. Select a risk model that estimates probability of decompression sickness values in line with the past dive profile results

3. Run computers against the test profiles
4. Assess general computer response
5. Use risk model to calculate probability of decompression sickness of the dive computer decompression schedules
6. Determine if the probability of decompression sickness risks associated with the dive computer for this type of profile are acceptable

Dive computer is a safety-critical system, while computers' manufacturers categorize them as personal protective equipment (Sieber et al. 2011). Therefore, functional safety must always be present, meaning that in case of failure, no harm occurs. Leveson (1995) states that design methods of reliability engineering are not sufficient for the design of safety critical systems. While some computers' manufacturers align their products with the safety measures and certifications, unified validation procedure and even techniques are necessary to ensure total and continuous safety. It is clear that there is no harmonized way of testing and certifying dive computers, probably because there are no standards or normatives that could be used for certification of dive computer (Sieber et al. 2011).

2.2.3. Demonstration

The framework results should be clear and distinct in this phase. Feasibility and efficacy of the framework should be visible and recognized before the evaluation phase. The demonstrated framework should be easy to use, mistake and failure proof (at least the risk should be minimized), flexible, trackable, and easy to implement. As mentioned in the beginning of paper, the final framework should be simplified enough in order to be understandable from a non-diving point of view. Furthermore, demonstration of the framework should satisfy three mentioned criteria of design science research methodology.

The framework should be consistent with the prior research and practice in underwater diving and related disciplines. Additionally, the framework should provide a nominal backbone process for future research. Moreover, it should also provide a mental model for research outputs. Consistency with prior research will be discussed furtherly in literature review. A mental model is a person's intuitive understanding of how something should function in the real world (Anderson, 2021). Mental model will assist and facilitate in two-way understanding – audience in reading and author toward readers. Richardson et al. (1994) addresses the following ideas regarding the model-based research on mental models:

- Mental models are multifaceted
- Brunskwikean lens model – extends over 'perceived state' of system
- Operator logic and design logic – should be manageable
- Mental models uncertainty – models are not directly accessible and/or observable

On the other hand, practical and technical benefits of a dive computer and proposed framework should be clear, recognized and understandable. Savings on time, decreased human error, extended dive times, enhanced focus on experience, safe descends and ascends, understandable media, extensive possibilities, gas integration are just some of the benefits which will be explained furthermore throughout the paper.

2.2.4. Evaluation

Even though the feasibility and efficacy of the framework should be visible in the previous phase, the framework will be evaluated. Through observation and measurement, there should be quantitative and qualitative factors that prove framework's effectiveness. Evaluation will provide an insight on how well the framework is actually a solution to the given problem.

There are four ways, in ascending order of practical value, to decide if a computer is physiologically acceptable (Edmonds, 1995):

- Testimonials and personal experiences by using satisfied customers as spokespersons, but the repeated diving of the computer to the limit is often lacking
- Compliance with decompression theories if there were unanimity of opinion on a single theory of decompression and no empirical modifications to dive tables
- Compliance with established diving tables, although progressive table modification has deleted unsafe profiles, and if decompression for same single and repetitive fixed-level profiles were comparable
- Comparison with hazardous diving profiles recognizing that there exists minimal information on safety limits of multi-level diving and even less information on decompression and repetitive deep dives

All the outputs mentioned in the demonstration phase should be visible and measurable during evaluation. Ultimately, the framework would be considered as a success if it offers a solution to the explicated problem mentioned in the first phase. In meantime, all the requirements should be distinctively evaluated. A very good thing is a lot of small things done well.

Sonnenberg and vom Brocke (2012) state that evaluation activities of an artefact are done quite late in the process. Rather, they propose a high-level cyclic process where every DSR step is followed by an evaluation activity.

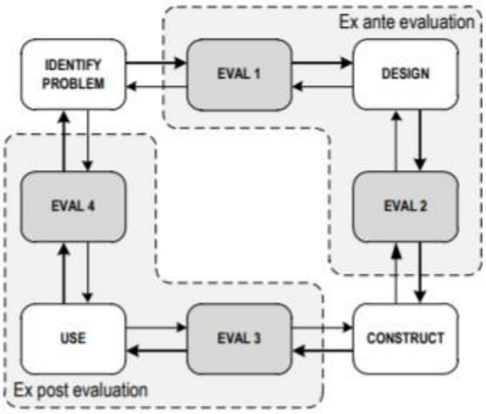

Figure 2 - Evaluation activities within the DSR process (Sonnenberg et al. 2012)

2.2.5. Communication

The problem and its importance are to be communicated, the artefact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences, such as practicing professionals, when appropriate (Peffers et al. 2006). Empirical research process, literature review, hypothesis development, data collection, analysis, results are also to be discussed.

A general structure of the framework should be followed by discussion. Paper should be finalized with delivery of the framework to the audience, with its benefits, outcomes, shortcomings and limitations. Ultimately, but not restricted to, the paper shall be successfully defended as a master's graduation thesis at the NOVA IMS school.

2.3. Research Strategy

Scientific research is a study that should be systematically planned before performing them (Caparlar, Donmez, 2016). A research strategy refers to the step-by-step plan of action that gives direction to the researcher's thought process, with its main purpose to introduce the principal documents of the study such as research topic, areas, major focus, research design and the research methods (Walia, Chetty, 2020).

Therefore, the purpose of using the given methodology is to have systematic, scheduled and thoughtful process which will be used in the artefact development. A good system artefact design must make a clear contribution, not only to target problem solving and its practices, but also to produce interesting methodological contributions to particular IS design theory (Miah, Kerr, Gammack, 2009).

Classical design approaches, such as traditional system development and prototyping, provide little support to system developers for conveying the methodological contributions for system design (Miah et al. 2016).

As mentioned, it is necessary to apply theory and practice from other areas and disciplines to solve certain problems; therefore, as scuba diving has evolved as a scientific discipline with assistance from other areas such as physiology, IT, marine sciences, etc., this type of methodology suits the topic perfectly. One of the goals would be to move from traditional descriptive research to interpretive research paradigms.

Every researcher trained in the culture of social science research has mental models for empirical and theory building research that allow the researcher to recognize and evaluate such work, and perhaps one for interpretive research as well (Peffers, 2008). All research is based on some underlying philosophical assumptions about what constitutes 'valid' research and which research method(s) is/are appropriate for the development of knowledge in a given study (Antwi, Kasim, 2015). Therefore, within this paper, qualitative and quantitative methods from different fields will be used to elaborate the matter further.

3. LITERATURE REVIEW

Literature review has served as a method for surveying all the literature, necessary and unnecessary, for the chosen area of study/ies. Then, all of the content had been synthesized into a summary, in which there was a selection of relevant and quality material needed for the development of thesis. With a selected relevant material, the content was followed by critical analysis. Critical analysis provided information on gaps, limitations and shortcomings in current knowledge among both scientific and non-scientific communities. It also provided directions for further research, which areas are well researched and which are not, and how the paper and its literature should look like in terms of form or structure. After the very review, certain trends in scuba diving and related areas have come up.

The summary of current findings is that diving industry is driven by technical, technological and performance-oriented products and services. Nature of scuba diving is characterized by safety and thus technology is developed thereafter. Major technological breakthroughs have happened in the last 20-30 years and technology substituted sheer strength and determination. During the last century, divers were relying on lucky wildcard which is not the case anymore due to scientific and technological research.

Diving industry is a niche industry, which means that specific segment of people are doing specific set of activities. The global recreational scuba diving equipment market size was valued at $1.95 billion in 2019 and is expected to reach this level again in 2023, post-pandemic recession (Darcy, 2022). There is an ongoing question on how far we have got in terms of diving innovation when it comes to safety and experience. The level between core and casual divers is equalizing, where number of core divers is shrinking, while number of casual divers is increasing. There are 30 million certified divers just from two out of dozen of most notable dive training associations (PADI, 2021; DEMA, 2021). PADI and SSI hold approximately 10,000 dive centers in around 150 countries (PADI, 2021; SSI, 2021).

Main type used for this literature review will be the narrative literature review. Narrative literature review entails gathering and summarizing the publications used in the process of the research development.

According to Caparlar et al. (2016), literature used in scientific research can be classified in regards to data collection techniques, causality relationships and medium through which research is applied.

Classification of literature research:

- According to data collection
- According to causality relationship
- According to medium through which research is applied

Literature sources for this paper are many. We will try to distinct them again and classify them into several categories. Main ideology while looking for appropriate literature was having a formulated and clearly defined problem inside the research which author tends to grapple with, research perspective and orientation, research methodology, and certain relation to the topic we are dealing with at the moment. Source categories are as following:

- Databases – used for finding scientific work, industry and sport analytics, statistics (NOVA Discovery, RUN Repositorio Universidade NOVA, Scopus, Web of Science, Google Scholar, EBSCO, ProQuest, Springer, Research Gate)
- Relevant diving associations – having access to most notable diving associations in the world in order to use material related to underwater diving (PADI, SSI, DEMA, TDI, SDI, CMAS, NAUI)

Relevant institutions not essentially related to diving – as mentioned, having complementary material from other areas - manuals, tutorials, manufacturers' information (US Navy, Suunto, Shearwater, etc.)

3.1. Types of Literature Review

Main type of the literature review used is called the narrative literature review. The main purpose of this type of review is to gather and summarize the publications used in the process of the research development, via appropriate data collection methods.

The general assumption has been that potential audience does not have prior knowledge of this industry. Therefore, the final framework should be perfectly clear to understand from the non-diving community, even though through the development of this paper there will be scientific and technical terms used. Hence, through extensive efforts, the intermediate work must be systemized and conceptualized by the conclusive part in order to achieve this objective.

Having above mentioned in mind, it has been repeated that scuba diving is relatively young sport, and despite the fact that it has developed as a solid independent discipline, complementary material coming from many other areas has to be used. Albeit scuba diving has an established history as a mean of scientific research, the interest in developing research on the topic of diving has been scarce, probably due to the increasing interest in recreational diving (hence, need for it to commercialize and suitably market).

Apart from the narrative type of literature review, we mentioned the classification of the literature research. Caparlar (2016) defined that the literature research can be conducted according to data collection, causality relationship and medium through which research is applied.

Classification of literature research:

- According to data collection
  - Observational – current trends in diving industry, practical findings, trends and changes in two environments - underwater (habits and practices while diving) and out of water (business point of view, tourism, sports and nature preservation management)
  - Experimental – practical underwater research, development of new ideas regarding technology, technical reviews, comparisons, quality testing and assurance
- According to causality relationship
  - Descriptive – general knowledge on diving industry and practice (from non-diving point of view)
  - Analytical – extensive information derived from deep studies, statistics, research analysed and explained in detail
- According to medium through which research is applied
  - Social – recreational diving community and diving as a leisure activity
  - Business – financial and marketing point of view (commercial diving, dive centers, dive tourism, etc.)
  - Sports – development of sports disciplines (world records, sport diving, spearfishing, etc.)
  - Regulatory – regulations, legislations, associations, etc.
  - Science – diving for the purposes of scientific findings

3.2. Review of Safety and Health Monitoring in Scuba Diving

Safety must be of primary importance in all diving activities, regardless of its nature. The priority has to be to conduct such activities in a manner that provides maximum safety to all participants involved. As stated throughout the paper, diving is a safe activity. But, as in any underwater activity, there are inherent risks that can never be completely eliminated. Therefore, having sufficient amount of training and knowledge, especially regarding the safety aspect of diving, is required in order to enjoy the experience and mitigate the risks.

The success of any diving operation is a direct result of careful and complete planning (Harris, 2006). In order to conduct a successful dive plan, participants must comprehend a series of factors that will take before, during and after dive. Researchers and diving professionals agree that three types of analysis must take place before a dive to fulfil the satisfactory level of diving safety: dive hazard analysis, dive planning, and emergency procedures.

Zayas (2020) states that dive hazard analysis must include the dedicated emergency phone numbers, planned depths and no-decompression limits, mode of diving, altitude and its depth corrections and environmental conditions (currents, visibility, water and air temperature, etc.). According to Fletcher (2011), dive planning entails operational/recreational objectives, dive site description, diving mode selection, full acknowledgment of diving conditions (both on surface and underwater), gas supply requirements, thermal protection, diving equipment and support needed, no-decompression limits and ascend/descent plans. Emergency procedure will vary depending on the nature of an accident, but most of the contingency plans must preach to: keep calmness and do not panic, commit to rescue action if necessary, stabilize patient as soon as possible, administer 100% oxygen at the surface, have diving physician or DAN (diver alert network) ready for assistance (Harris, 2006).

3.3. Review of Technology in Scuba Diving

Diving, as a profession, can be traced back more than 5,000 years. Early divers confined their efforts to waters less than 100 feet deep, performing salvage work and harvesting food, sponges, coral, and mother-of-pearl. A Greek historian, Herodotus, recorded the story of a diver named Scyllis, who was employed by the Persian King Xerxes to recover sunken treasure in the fifth century B.C. (US Navy, 2016).

From breathing tubes, breathing bags, diving bells, diving dresses all the way to today's open and closed-circuit breathing apparatus, technology in scuba diving has come a long way through the history. The pinnacle of the historical development of technology in scuba diving happened in middle-end of WW2, where French duo Jacques-Yves Cousteau and Emile Gagnan came up with the first truly efficient and safe demand regulator with the open-circuit self-contained breathing apparatus, called Aqua-Lung. The Aqua-Lung was the culmination of hundreds of years of progress, blending the work of Rouquayol, LePrieur, and Fleuss, a pioneer in closed-circuit SCUBA development. Cousteau used his gear successfully to 55 meters depth without significant difficulty and with the end of the war the Aqua-Lung quickly became a commercial success. Today the Aqua-Lung is the most widely used diving equipment, opening the underwater world to anyone with suitable training and the fundamental physical abilities (US Navy, 2016).

Some crude designs of dive computations were attempted in the first half of the 20th century. In 1955, American manufacturer Foxboro came up with the first analogue dive computer – Decomputer Mark I, in which the needle is hovering in the red zone in case of danger during ascent (Kutter, 2014). In 1965, Robert Workman of the US Navy Experimental Diving Unit publishes a first algorithm for computing decompression requirements suitable for implementing in a dive computer, rather than a pre-computed table (Workman, 1965). It was for the first time that somebody provided a theoretical basis for calculation of decompression schedules for nitrogen-oxygen and helium-oxygen mixtures used in diving. In the late '70s, dive computer went digital and experienced great technological breakthroughs. The outcome of that was the Orca Edge, which emerged in the market as the first commercially viable and safe dive computer in 1983 (Computer History Museum, no date). Fast forward to today, dive computers are advanced and essential diving equipment which allow diver to monitor current depth, maximum depth, bottom time, current time, temperature, gas mix stats, ascent rates and provide guidelines for performing safety diving.

To validate dive computer models, diving data is necessary (Westerfield et al. 1994). In order to do that, Wienke and O'Leary (2018) propose that data collection is an ongoing effort, where profile information can be narrowed down to its simplest form, most of it coming from dive computer downloads tagging information across variable time short intervals, which is then processed into a more manageable format needed for statistical analysis.

In the end, a dive computer should be capable, deployable, maintainable and useful. Capability of a dive computer entails that its system should have enough power and essential features to perform or assist a diver in his performance; high level of deployability should provide ease of movement installation and implementation of the equipment; a dive computer should be maintainable to the degree that it preserves its operational condition; lastly, usability of a dive computer relates to the quality of diver's experience (US Homeland Security, 2013).

3.4. Challenges of Literature Review

The very topic of this paper is challenge-driven, as the paper tackles a topics that are not necessarily in the primary focus of scientific research. Great efforts have been put in order to avoid lack of relevance, lack of transparency, and lack of evidence provided by the 'grey' literature. Therefore, the research with high standards of critical appraisal in research has been used, in which we are able to identify the methodologies and outcomes previous authors have used and come up with.

As mentioned, scuba diving should be a recognizable backbone of scientific research. Thus, one shall think that the topic of diving is well presented in scientific research. But, that responsibility has been taken by diving professionals who, through the diving education and similar activities, are setting up a well-defined standards on scuba diving practices and policies. Main challenges that we will elaborate in this chapter are lack of high-standard research in the area of scuba diving (1), conservatism versus liberalism in technology used in scuba diving (2), and major actualities about utility of scuba diving technology which produced some additional questions to be answered in writing this paper (3).

3.4.1. Lack of Scientific Research in Scuba Diving

Understanding of the underwater world has always been in the focus of humans. Considering a fact that Earth is 71% water-covered, that desire for understanding makes a lot of sense. However, Marsh (2017) states that only 5% of the ocean has been explored, out of which 0.05% has been mapped. On the other hand, Marsh says that Hubble Telescope allows people to see up to 13 billion lightyears away in the cosmos, and since 1969, we have sent 12 people to the moon, while during the same time – only three people have explored the deepest part of the ocean.

One of the most popular scuba diving organization, SSI, provides the course called Science of Diving. This course will equip divers with an in-depth theoretical and practical understanding of diving physics, physiology and oceanography. That knowledge is essential for anyone who wishes to involve in the world of diving as a professional. Contradictorily, on Google Scholar, when filtering search for the research published in the last ten years, we get a result of approximately 22,000 papers, out of which there are many papers unrelated to the area of diving (typos: deep dive into the machine learning; diving through data; etc.).

After the emergence of technology used in scuba diving, sea has become more accessible for everyone. As with everything, that was a chance for commercialization of scuba diving with primarily profitable goals in mind. After taking that chance, scuba diving has started being categorized under travel and hospitality industry, while at the same time that produced a mitigation of diving's importance in scientific research. Timur (2015) states that scuba diving is actually a rather young niche, but it should not be viewed in isolation and it must be contextualized. That lack of contextualization in scientific research has been causing the lowered standards in scuba diving, which must not happen in order to fulfil the maximum level of safety.

3.4.2. Conservatism versus Liberalism in Technology Use

Dive computers are based on theoretical models – algorithms. Meaning that they are not suited to the individual who uses a computer but are based on experimental overall & general data and theory on nitrogen absorption under pressure. That results in some dive computers being more conservative (less diving time, more cautious in calculation), while some dive computers are more liberal (more lenient – more diving time, higher risk of adverse events). There is no evidence that divers using computers with more liberal algorithm settings are less safe than the ones with more conservative setting. Hence, the setting does not make one safer than another. Rather, the issue is in the arbitrariness of calculation because the characteristics and state of a specific diver are not taken into account.

In general, you can trust in the effectiveness of all dive computers available on the market nowadays. High-end computers even let you set a gradient factor of conservatism depending on conditions of one's dive. However, the choice and preference are not united in diving community or in instructional manuals of computer manufacturers. That causes a certain problem, especially with an unexperienced divers.

Dive computers are wonderful at carrying out programmed mathematical computations, but they are blind to the many insights you may have before, during and between your dives (Denoble, 2013). Therefore, it is not enough to blindly rely on a dive computer. That is one of the reasons of my efforts to propose the framework.

3.4.3. Recorded Problems in Using Technology

In this chapter, we will take a look at two examples of problems caused by using dive computers, which provided a challenge that this paper aims to tackle by proposing a holistic framework. Lawsuit against Suunto, Finnish diving gear manufacturer, in which two divers had recognized the malfunctioning of Suunto's dive computers, which is believed to be a direct cause of one diving fatality (1). Also, an experimental study reviewing the functioning of 47 different dive computer models, which showed that technical capacity described by manufacturer could not be actually replicated and that some data collection discrepancy happened, will be elaborated (2).

In 2015, two plaintiffs, Eric Bush and Ralph Huntzinger, decided to sue Suunto (more precisely – Suunto & Aqua Lung joint venture which was in charge of selling and servicing Suunto's diving gear in the US market), because of the alleged malfunctioning of 18 different dive computer models (Superior Court of the State of California, 2018). Speaking to other divers, plaintiffs discovered that the failure of Suunto's gear had been common. It is feared that the unfortunate end result caused by hardware and software, which was shown to be defective, was a diver's death in 2010 in Hawaii, where computer presented that diver had plenty of air left, while in reality it had run out. Trial resulted in settlement of $50 million intended for testing, repairing and replacing mentioned dive computers, with additional $775.000 fund directed for compensation to divers who were using those computers.

Everybody participating in dive industry must be highly cautious of negligence and any breach of health & safety protocols. It seems unbelievable how probably the two biggest diving brands and pioneers in diving industry allowed the breach of warranty. But, that just shows the continuous need of maintaining awareness on the safety aspect of diving. If those two plaintiffs didn't realize the malfunction, we could wonder how long and great impact of that malfunction would be. Another reason why such framework that this paper will propose is extremely needed in diving industry.

In the second case, we will take a closer look at a study in which 47 different dive computers were tested and reviewed in regards to their data collection, depth recording and measurement, decompression and gas settings, and other features. Azzopardi and Sayer (2010) concluded that some of the computers could not replicate the technical capacity as stated by computer manufacturer. They also said that the technological development of dive computers has come in a small number of very distinct phases that are linked with concomitant advances with corresponding technological development (e.g. micro-processing power, storage capacity and volume, battery performance, sensor miniaturisation).

The problem here is that this kind of evolution is keen to produce adverse outcomes which will be closely related to general misunderstanding on how dive computers work. Increasing diversity in dive computers market could also be a risk factor, but it is certain that dive management practices must be based on clear understanding of how the dive computer works. A challenge which we will try to tackle throughout the development of this paper.

3.5. Opportunities of the Literature Review

After convening and realizing that challenges in this area are many, opportunities are no different. Opportunities can be understood as a counterpart of the challenges mentioned, but as we mentioned, scuba diving is an ever-evolving discipline which requires constant development. Therefore, the opportunities that we will elaborate further are both related to the research suitable for the disciplines concerned and revision and relatively feasible advancements of a diving industry in the future.

Derived from the review of the literature used, summary of opportunities would be to provide a high standard verified staple for the future research, analyse the development possibilities of dive computers and corresponding diving technology, and comprehend the future of the decompression theory with a focus on mitigation of its risks and trying to deploy its factor in the favour of diving.

3.5.1. Future Research

There is not a lot of information, both quantitative and qualitative, by which to assess the recent importance of diving to the scientific community. On the other hand, almost all of the reef scientific research is done by scuba divers. Largest coral reef research, Global Reef Expedition, has done more than 12.000 dives and covered more than 65.000 square kilometres in last five years (Purkis et al. 2021). Scientific diving is in charge of researching some of the most essential topics nowadays, such as climate change, ocean acidification, ecosystem functioning, paleoclimate reconstruction, etc. The importance of scuba diving in terms of science should be more recognizable and should serve as a backbone for further research. Science and related research must persist in a pursuit of decompression, technological and similar advancements.

By conducting this research, one of the goals of this paper would be to help people address the problems in practicing diving and increase safety for the future. Considering the impact of diving to science, every diver can be a stakeholder in observing and gathering data needed for underwater research. Underwater world should be more accessible and familiar to everyone, regardless of their background.

3.5.2. Future of Scuba Diving Technology

The age of electronic diving has arrived with the development of the modern electronic dive computer as the most significant advancement in self-contained diving since the invention of the Aqualung by Jacques Cousteau (Lang, Angelini, 2008). New technologies such as wireless transmitting to the surface board control, underwater user interface, communication, distress technology, etc. are certainly areas in which research must improve.

3.6. Systematic Literature Review on the Use of Technology in Scuba Diving

In order to systematically summarize the literature reviewed, which has included numerous content and the content left out from the paper from various sources, holistic report is essential to make sure that everything has been accounted for. For that purpose, the PRISMA Statement will be used.

PRISMA Statement (The Preferred Reporting Items for Systematic reviews and Meta-Analyses) is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses. It primarily focuses on the reporting of reviews evaluating the effects of interventions, but can also be used as a basis for reporting systematic reviews with objectives other than evaluation. Ultimately, PRISMA Statement should provide a ground for facilitation of evidence-based writing.

The overview of the concepts concerned that will be elaborated in this paper defines the structure of the investigation and solution development. Thus, a systematic review such as PRISMA is needed to deeply understand previous, current and potential trends, rules, policies, procedures, etc., which provides a holistic hindsight of the topic and future work related. To achieve mentioned, following research questions are raised:

- Q1 – What is the current state of the scientific research in scuba diving?
- Q2 – What is the current state of the technology research in scuba diving?
- Q3 – What is the current state of health & safety research in scuba diving?

To answer these questions, a certain selection and review of relevant studies has been conducted. Great challenge is presented through using the word “deep”, where we received a lot of typos unrelated to the fields of underwater diving, technology, safety, etc. Around 22.000 papers were initially screened through the selection of the following keywords:

KEYWORDS	RELATED SEARCH
Scuba diving	General overview and hindsight of the topic
Diving technology	Technology involved
Dive computer	Specific technology elaborated in this paper
Dive safety	Safety and health procedures and policies

Table 2 - Keywords

The part of the PRISMA Statement, the flow diagram, depicts the flow of information through the different phases of systematic review.

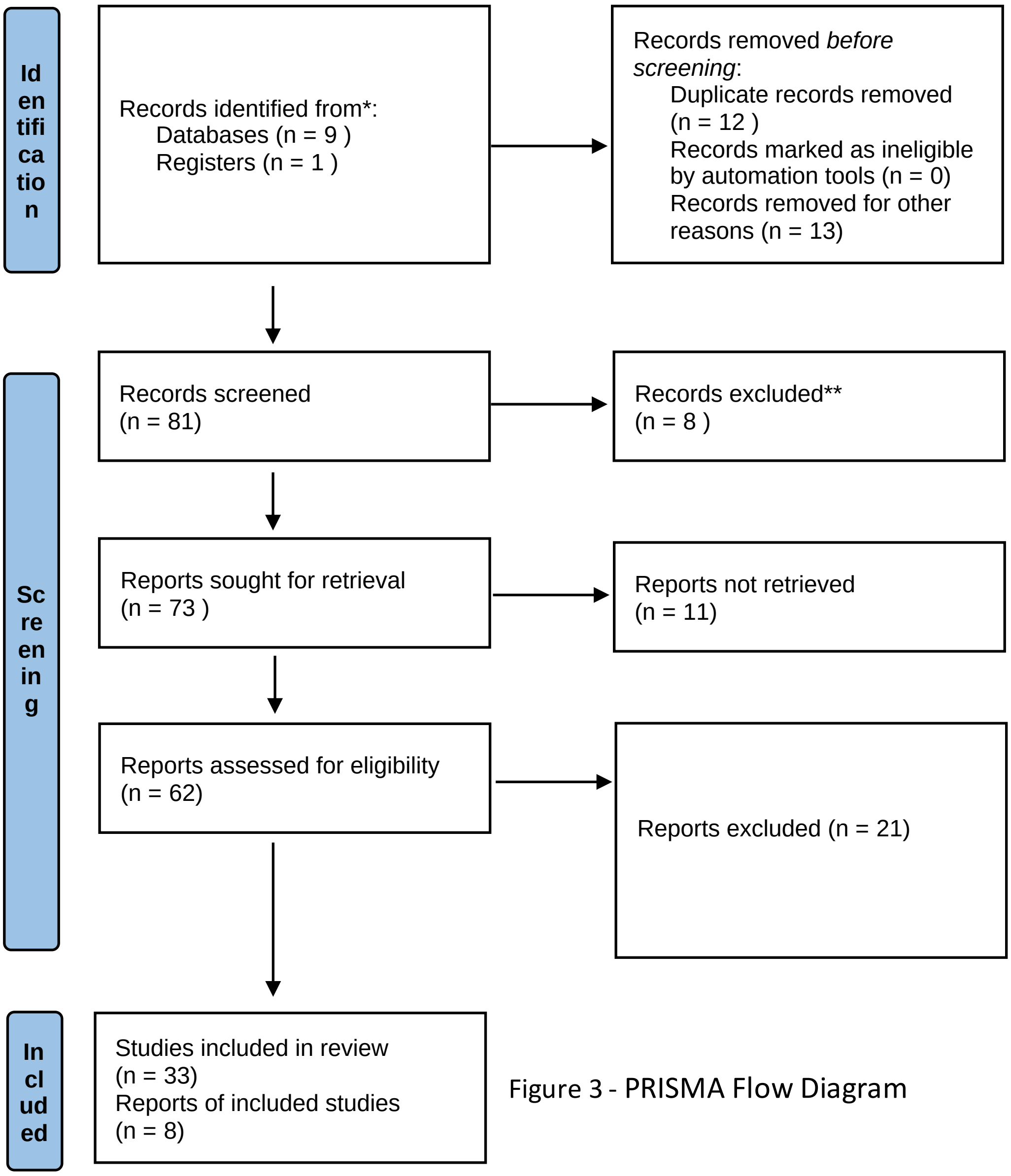

Figure 3 - PRISMA Flow Diagram

4. FRAMEWORK CONCEPTS

The conclusive purpose of doing literature review is to have a foundation for knowledge needed for the development of this paper. The knowledge is a backbone of any work, thus this literature review is an essential element for writing the dissertation. More precisely, this dissertation will propose a framework. Therefore, proposal writing cannot be conceded without a solid and structured literature review.

Concepts of the literature review are critical components of the research process that provides an in-depth analysis of comprehensive research findings in chosen areas of interest (Houser, 2019). The concepts in this work have been summarized and developed from different perspectives and areas. Different ways of data collection and verification, causality relationships between data and literature, mediums through which research is applied, categorizing and describing content which is relevant to the research, etc.

The literature review and conceptual frameworks share five functions: (a) to build a foundation. (b) to demonstrate how a study advances knowledge, (c) to conceptualize the study, (d) to assess research design and instrumentation, and (e) to provide a reference point for interpretation of findings (Merriam, Simpson, 2000). Not all five of the functions are inescapably found in each artefact, but the goal is to satisfy as much functionality and conciseness as attainable while conducting the review.

4.1. SCIENCE IN SCUBA DIVING

The ultimate purpose of science in scuba diving is to comprehend the concepts which are relevant to understanding of the underwater environment, how a diver affects it and how it influences a diver. People not being underwater creatures, thus in those terms underwater being a hazard upon us, we have been stipulated to use and practice science in order to go longer and deeper underwater.

Diving has an established history as a research tool underpinning a considerable volume and variety of underwater science (Munro, 2005). Impactful studies have been done conducted by scuba divers which have produced discoveries in biology, geology, oceanography, ecology, etc. Various animal, plant and non-living object samplings, pollution studies, ocean observation, reports of new species, etc. have been provided by scuba divers. Recently, probably dues to the increase in the dominance of the recreational sector and a concomitant growth in the number of scientists diving for pleasure, scientific diving may be attracting a mixed opinion as to the quality and quantity of research that it supports (Sayer, 2007).

Scuba diving is essential to observe and study the complex dynamics of the ocean, which ultimately contributes to enhanced preservation of the planet, while sustainably exploring and exploiting benefits underneath the blue surface.

Sciences such as physics, physiology, oceanography, environmental, biology, etc. are a vital prerequisite in order to conduct any research or activity in diving, whether theoretical or practical.

Diving physics explain the effects that divers and their equipment are subject to underwater (Acott, 1999). Main laws that are taught for diving, but also needed for the development of this paper because it is impossible to elaborate the technology used underwater for the purposes of safety and enhanced experience without understanding the laws of nature behind it. Such laws are:

- Archimedes' law of buoyancy - when in water, the density of the materials in the diver's body and in the diver's equipment determine whether the diver floats or sinks (Taylor, 2022)
- Boyle's law - relation concerning the compression and expansion of a gas stating that the pressure of a given quantity of gas varies inversely with its volume at constant temperature (Britannica, 2022)
- Dalton's law – in a mixture of breathing gases the concentration of the individual components of the gas mix is measured by partial pressure (Acott, 1999)
- Pressure – the overall pressure on a diver is the sum of the atmospheric pressure and the water pressure
- Thermal and vocal conductivity of water is higher in the water than that in the air
- Under pressure gases are compressible but liquids are not – air spaces inside the one's body and inside the one's equipment shrink as the diver descends, therefore expands when one ascends

As an example, major scientists in this field, such as Fleuss, Bert, Smith, were not aware of the serious problems of oxygen toxicity caused by breathing 100% oxygen under certain pressure. The true seriousness of the problem was not apparent until large numbers of combat divers were being trained in the early years of WW2, when after a number of oxygen toxicity accidents, people started experiencing massive convulsions and due to its impact on central nervous system and lack of hyperbaric medicine at the time, death was followed (US Navy, 2016). Now if we imagine that all above mentioned laws are systemized in the small wrist-worn computer through means of mathematical algorithms, we realize that impact of technology has been massive and essential on the development of diving.

After the initial technological advancements (crude but relatively effective at the time) in the early history of scuba diving, physiological discoveries were following them as the crudeness resulted in downsides and hazard-affecting cases during or after dives.

At the time, unexplained adversity started to affect divers. Upon returning to the surface, divers would be struck by breathing difficulties, dizziness and sharp pains in their joints. Such symptoms are caused by the disease we today know by the name of decompression sickness, or commonly called in diving community – "bends". Clinically described by Paul Bert in 1878 for the first time, he determined that breathing air under pressure forced quantities of nitrogen into solution in the blood and tissues of the body (US Navy, 2016). As long as the body is at the same pressure, the gas would remain in the solution. When the pressure is released, the nitrogen would return to gas state too quickly to exit the body in a natural way. That would result in gas bubbles forming throughout the body, causing the above mentioned symptoms.

Again, the relatively recent advent of affordable dive computers has changed the face of modern diving immensely (Donaldson, 2019). Traditionally, you would have needed to conduct a "mental math" and estimate how much bottom time you have, but simple watch-like system which can cost just around 100$ does the job precisely while also taking other fluctuations in real-time. Physiological differences in a body while being in the underwater environment are drastically different than being on surface, due to a breathing air (or complementary gas mixtures) under pressure, hyperbaric gas toxicity, sensory impairment, etc. In general, challenges of underwater environment are underappreciated, therefore it is mandatory to conduct the extensive research on how technology is contributing to a diver's wellbeing underwater. This paper will provide the overview on how the major environmental challenges are affecting divers and their equipment (including technology) by using relevant research in the area of physiology specified for the underwater environment and activities of diving.

Sciences of oceanography (in rarer instances, also limnology) has been used due to the many environmental hazards that underwater poses to a diver. Weather, sea state, surface visibility, underwater visibility, depth, bottom type, sea movement, temperature, contamination, altitude, marine life are just some of the hazards that represent threats to diver's wellbeing. All these are included and well researched throughout the last 30 years from the scientific point of view. Initially, great credit goes to the scientists and military personnel who were participating in diving, but as diving has become more and more popular and practiced, mentioned sciences and its correspondents have been specifically focusing on the environment and area of underwater diving.

There is little quantitative information by which to assess the recent importance of diving to the scientific community; while on the other hand diving supports scientific research through efficient and targeted sampling (including numerous new species and reports), quantitative survey, observing animal behaviour, making in situ measurement, undertaking impact studies, a variety of ecological analyses, the evaluation of new techniques, by mapping underwater areas, profiling subtidal geology, and by deploying and retrieving underwater apparatus (Sayer, 2007).

4.2. Technology and Technicality in Scuba Diving

Since knowledge and technology had been making underwater environment more accessible, scientists and tech professionals have partnered to create some of the most revolutionary tools for deep-water excursions (Donaldson, 2020). In the era of the wearable technology innovations, underwater world was not an exception.

The main function of dive computers (calculating a decompression profile of a dive) is based on predictive models that are prescribed through algorithms. Literature reviewed has been used to decrease conservatism when using a dive computer, even though that relatively models that manage decompression calculations are simple. The reason for that is that the same 'simplicity' level of confidence cannot be maintained if dive profiles are outside of the range of its applicability and normality.

Dive computers are essential in optimization of dive time and decompression, which will be the main technology elaborated throughout this paper. Literature used has provided a scientific and technological insight into the decompression models, analogue to digital metric converting, microprocesses inside the dive computer, but most importantly – what does algorithm provide and how it assists a diver? Therefore, algorithms which will be elaborated further in the paper are the three most represented by dive computer manufacturer, which are: Buhlmann's, RGBM and RDP (Spencer/Powell).

4.3. Performance and Experience in Scuba Diving

Scuba diving is an exciting sport, but attempting it without the proper training and knowledge will result in adverse outcomes. That is why instruction professionals are emphasizing the importance of practicing the using of technology. Therefore, this concept is related with the technological & technical because of problems happening when handling the technological and technical aspects are substandard.

Throughout the evolution of diving, from the earliest breath-holding sponge diver to the modern saturation diver, the basic reasons for diving have not changed. Military, commerce, science and leisure continue to provide the underlying basis for the development of diving. What has changed and continues to change radically is diving technology. Each person who prepares for a dive has the opportunity and obligation to take along the knowledge of his or her predecessors that was gained through difficult and dangerous experience. The modern diver must have a broad understanding of the physical properties of the undersea environment and a detailed knowledge of his/her physiology and how it is affected by the environment. Divers must learn to adapt to environmental conditions to successfully carry out the dive. Much of the diver's practical education will come from experience (US Navy, 2016).

Therefore, in order to attain the highest level performance and experience, it is essential to seek, gain and apply the knowledge, both theoretically (all the institutions training recreational and technical diver require extensive knowledge on the topic mentioned in the Scientific Concept) and practically (technical and general practices, technology utility, etc.). Also, Scuba Schools International (2021) states that the more physically fit you are, the better able you will be to adapt to the underwater world. Physical fitness is often overlooked component in diving.

On the other hand, if we perceive and understand experience as an occurrence that leaves impression on individuals participating in diving, certainly we can hear that for each diver immersing underwater bring something tremendous. We can safely conclude that people dive because of the feeling experienced. So, existing literature will provide the indications on what needs to be done in order to live through the peak experience of one diver, by means of theory and practices needed to go through it.

Performance is measured by the quality standards of practices taking place while diving. Persistence in those practices is a key factor since the contact with the water until resurfacing and going back to dry land. Managing perfect buoyancy, not overspending the gas tank, not damaging the environment, being able to handle unplanned events, are all factors that one diver needs to perfect. That perfection, rather it being a journey than destination, is a process of enhancing through the diving career, whether recreational or technical.

Planning is a very important part of scuba diving. Failure to plan can place you in a difficult situation underwater. A properly trained diver is less likely to panic, and will be able to resolve difficult situations underwater in a calm and methodical manner (SSI, 2021).

4.4. Health and Safety in Scuba Diving

In general, there are some sacred rules in scuba diving that all health and safety measures are relied on, such as: never dive without a buddy, double-check gear of yourself and your dive buddy, never dive when you don't feel like it, etc. If we take a look at all medical recommendations regarding diving, they will all propose the measures mentioned in the chapter of scientific concept. In recent years, specific area of physiology has been developing and focusing on adverse consequences. Therefore, researching safety in scuba diving without interference of suitable disciplines concerned with health & safety is not feasible.

We can conclude that all the risks and undesirable outcomes in scuba diving are related to health and safety aspect. All the problems happening underwater lead to issues in this area. Diving certification courses are maximally focused on preventing, or at least lessening the risk of diving-related adversity. As Moon (2021) states that scuba diving is a safe sport and activity for healthy people who have been appropriately trained and educated, Angelini

(2021) is persistent saying that one should not leave his/her training limits and own's limitations. On the other hand, two pathologists, Lawrence and Cook (2006) stated that, out of undisclosed number of fatalities happened during scuba diving, 86% of them happened due to the inability to swim, panic (inadequate training), intoxication, nitrogen narcosis, seizures, natural diseases (acute infarcts, asthma, epilepsy), entrapment and physical disability. After detailed pathology reports, we can see that adversity is preventable.

Literature reviewed aligns that scuba diving must continue requiring proper safety standards to minimize risks. However, greater responsibility by both individuals and organizations participating is needed in order to attain a satisfying framework of safety measures.

The literature supports the positive link between divers and their safety attitudes and behaviours. Surveys show that scuba divers tend to be responsible underwater, to participate in safety measures and to respect a defined compliance [(Lawrence, Cook, 2006); (Sayer et al. 2008); (Ong, Musa, 2012); (Pinkowska et al. 2020)]. However, Lucrezi et al. (2018) reports that, out of 208 divers questioned for the survey, 30% of them have experienced some sort of accident which was preceded by some risk-related behaviour activity.

Surely, it is up to responsibility of divers and dive centres to maintaining adequate diving code of practice, managing safety measures and indications, and respecting all the factors of training, limits and environment. Stress and strain imposed by the underwater diving are unique and challenging, and in extreme cases dangerous (Pendergast, Lundgren, 2009). Therefore, current and future research in fields concerned with diving must be tackling an ongoing affair with health and safety; which up to certain degree, this paper aims to do so.

4.5. Understanding Dive Computers

Dive computer is a battery powered, pressure-resistant device which provides real-time information on depth, elapsed time, temperature, etc., but most importantly it assists divers in attaining low or no risk of decompression sickness by using decompression algorithms.

Figure 4 Cressi Michelangelo console (left) and wrist-worn (right) dive computer (Cressi.com)

Two main input processes of a dive computer are tracking of time and pressure. Every computer measures ambient pressure, which is automatically translated into the value of depth below water. The pressure increase per one meter of descent in salt water is 0.1 bar; therefore every 10 meters = 1 bar (for fresh water: 10.2 meters = 1 bar).

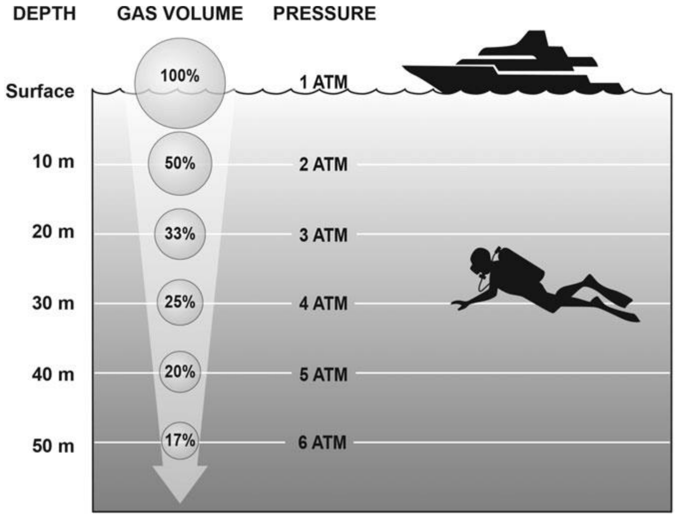

Figure 5 - Relationship between underwater depth, gas volume and pressure (Mallen, 2019)

Apart from the reason of providing information on depth(s) to a diver, dive computers measure ambient pressure to model the gas concentration of the tissues in a diver. So, by continuously processing time and depth input through decompression algorithm, dive computers provide real-time information on partial pressure of inert gasses dissolved in a diver’s tissues. From the gas solution that a diver breathes, under partial pressure, particles of that solution are released in a diver’s body tissues. Oxygen molecules that one breathes become bound to blood by haemoglobin. Therefore, as the dive goes, gas dissolves into the blood plasma. However, next to oxygen, nitrogen as an inert gas has absolutely no use in the human body so it’s dissolved into body tissues when someone breathes gas under pressure. Nitrogen stores in tissues temporarily. Therefore, a human body requires slow rates of descents/ascents, safety decompressions stops, different gas solutions in order to saturate and avoid risk of getting decompression sickness, where a body doesn’t get rid of the residual inert gas. Decompression algorithm inside of a dive computer takes into consideration the proportion extents of pressure changes (increase while descent, back to atmospheric while ascent), time spent at altitudes, breathing gas mixes and changes, rates and speed of ascent and descent.

A dive computer consists of a watertight housing with a through-hull pressure transducer that transforms pressure sensed through an analogue-digital converter to the microprocessor, powered by a battery; read-only memory, random-access memory and a clock feed into the microprocessor which outputs information to a diver via the computer’s display (Lang, Angelini, 2009). The ROM contains the model programme (step application of model equations), all constants and queries, the transducer and clock; while the RAM maintains storage registers for all dive calculations ultimately sent to the display screen. Some 3-9 volts is sufficient power to drive the computer for a couple of years assuming about 100 dives per year (Wienke et al. 2018).

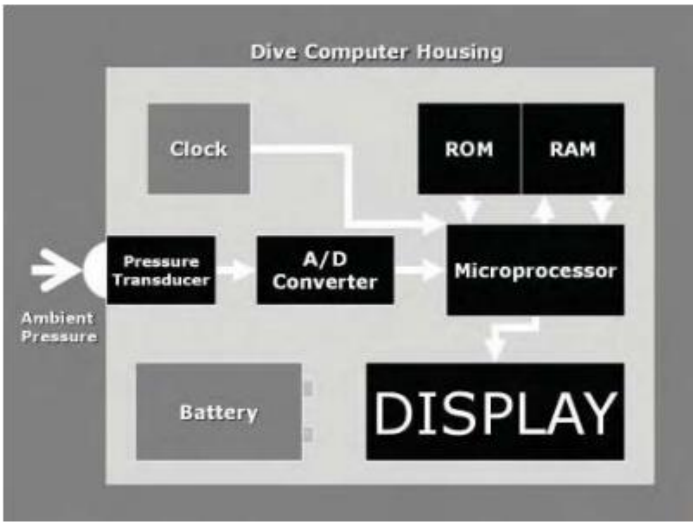

Figure 6 - Simplified dive computer housing (Lang et al. 2009)

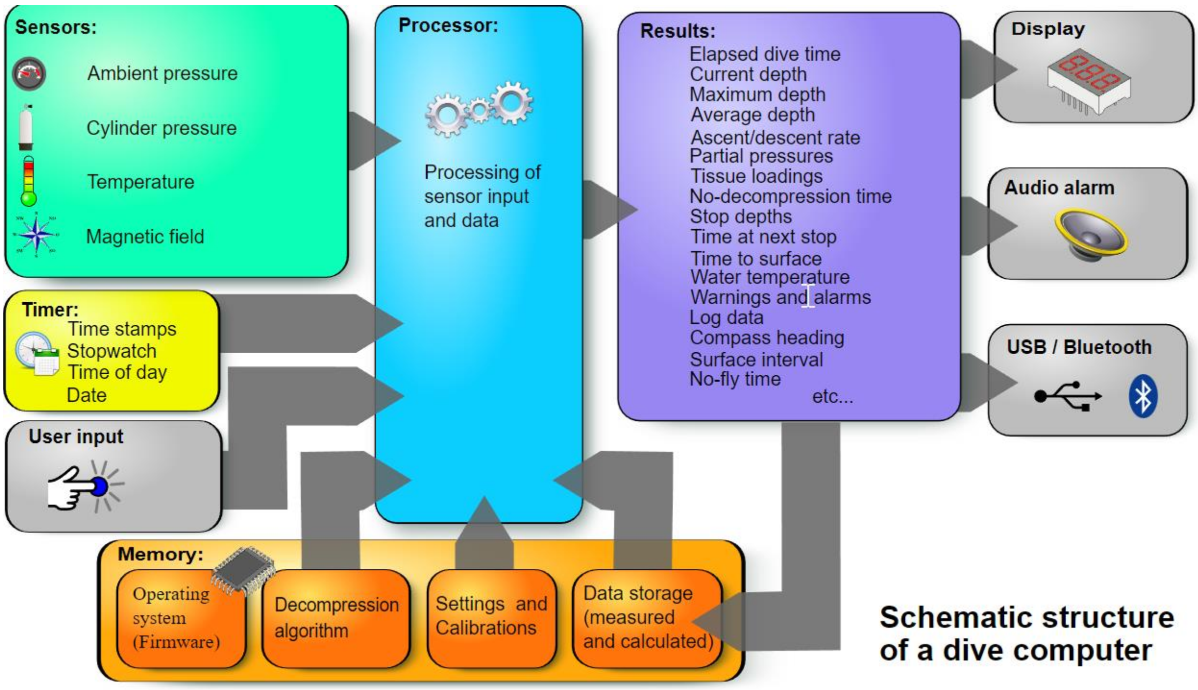

Figure 7 - Schematic structure of a dive computer (Blogg et al. 2012)

A dive computer calculates the depth every few seconds (0.5s-5s, depending on a computer's quality) based on its programmed decompression algorithm. Those algorithms provide operational ability to prescriptive models which furthermore provide operational functionality of dive computers. In essence, there are two types of decompression models: dissolved gas model and bubble models. In addition, there are probabilistic decompression models in which parameters of known statistical models are fitted to a set of empirical data concerning decompression illness incidences in subjects exposed to various decompression profiles (Angelini, 2018), but these are not commonly used in dive computers, therefore they will not be covered in this paper.

Dissolved gas model maximizes tissue supersaturation up to safe limits derived by experiment and adjusted based on past outcomes. The idea is that the more saturation there is, the more time body has to get rid of the inert gas that it has been collecting throughout the dive. On the other hand, bubble models relies on limiting tissue supersaturation early in the ascent to minimize bubble formation and growth according to models of bubble behaviour (bubble = nitrogen particle which is dissolved in a diver's body). The basis of a bubble model is that the smaller increments of supersaturation are enough to avoid the bubble formation. In layman terms, the greatest difference between these two models is: DGM proposes few longer stops, while BM proposes many shorter stops. No model is better than the other, but rather it is up to a diver to choose which model fits them more according to their style and type of the dive.

5. FRAMEWORK PROPOSAL

The ultimate goal of this paper is to construct a comprehensive framework which provides guidelines on how to achieve continuous safety and peak experience by using dive computers. This theoretical framework is consisted out of existing concepts in scuba diving and mentioned corresponding sciences which are included in diving practice. The framework must provide basis for understanding of its concepts and theories, that are relevant to the topic discussed, for its respective audience.

There is no a framework present, whether practical or theoretical, on how to universally use the dive computer in order to resolve diving issues, mitigate diving risks and/or improve your diving quality. After extensively reviewing existing literature relevant to the topic, we can conclude that the framework is highly necessary, but it should also be pertinent and appropriate to the ease of use, have viable application and high explanatory power.

Although the framework will pertain its theoretical nature, along with certain experimental additions, it should attain a decent level of applicability. Applicability is recognized through justified validation of the framework, and relation to initial identified problems which motivated the research process.

The framework is rooted in a specific theory. The theory is that scuba diving is characterized by health and safety, hence all technology is developed thereafter. It is only when all the essential safety guidelines are respected, a peak of experience can be granted and achieved.

Overally, the framework presents a conceptual and progressive structure that will serve as a guide and a support for ensuring continuous safety and peak experience.

5.1. Problems Preceding the Framework

The biggest problem a diver can have is to think that the dive computer guarantees safety. Dive computer is indeed a safety critical support, but its main function is to monitor a fraction of the dive situation. Also, regardless of a fact that decompression algorithms are based on an established decompression table, gas fluctuation under pressure is not yet fully understood from the medical point of view. The decompression of a human body is influenced by individual physiology, fitness and health condition. Divers should know that while the decompression algorithms in dive computers are great at measuring pressure-time profiles, they are blind to a wide range of variables that affect decompression risk. The approximation of decompression status predicted by current deterministic algorithms should not be confused with 'truth', even though they can provide reasonable guidance under normal circumstances of relatively conservative exposures. The next problem is determining what is really 'conservative'. The complex interplay of exposure, individual status, and individual response makes it difficult (Pollock, 2015).

Dive computer needs to be capable of handling decompression obligations at any time and, in case of malfunction, it has the potential to endanger diver's life. Taking that into account and also that dive computer manufacturers are categorizing their computers as a personal protective equipment, the lack of safety standardization should not be present.

Dive computers have become a standardized piece of divers' equipment. The ability and capacity that a computer possesses enables a diver to continually review and monitor their decompression status more efficiently. However, there have been very few human subject studies that were performed to validate the use of dive computers (Huggins, 2011). Therefore, a diving community is in need for the specific method to evaluate the associated decompression risk for the diving use.

5.2. The Framework – Ensuring Continuous Safety and Peak Experience

A major prerequisite to even commence using the framework is for one to be medically fit, sufficiently trained and properly certified. We have spoken about the importance of that prerequisite before. No framework will keep a diver out of inherent danger that diving brings to them. Only after the prerequisite is obtained, one should start practicing and applying the following framework.

Overally, the framework presents a conceptual and progressive structure that will serve as a guide and a support for ensuring continuous safety and peak experience.

To finalize all conducted research and development, the summarized framework consists of three steps:

THE FRAMEWORK	
1. Technology knowledge and familiarity	- A diver must obtain sufficient knowledge on what's happening inside and outside of a dive computer before, during and after a dive. There must be a decent level of familiarity on decompression theory, conservatism levels and influence of underwater environment on dive computer. - Confidence > Panic – When a diver continuously works on their diving technology, only then they are able to handle it purposefully, effectively and with confidence. In a life-threatening situations, high level of confidence comes only from a proven accumulated skill of dealing

	with those kind of situations (may be imitated). - User manuals – Every dive computer manufacturer is obligated to provide suitable manual instructions on how to handle their technology. A diver must be 100% familiar with all the details that technology producer deemed to be relevant for the maximum utility of dive computer. Only then, a diver will be able to handle all the utilities and limitation of underwater environment.
2. Practical and applied use of technology – 5 limits	- Conservative limit – A diver must conservatively use and perceive the data displayed on a dive computer. Conservatism will provide a cautionary method where reaching any kind of limits (whether listed here or not) will be hardly attainable. Modern dive computers have customizable gradient factor setting of conservatism vs. liberalism of their decompression models. This framework advocates having moderate to high levels of conservatism as an obligatory. - No-decompression limit – A pre-dive plan must be followed. This time period presents a diver with a time interval at which they can spend time underwater, whether with decompression stops or without. - Time limit – Elapsed time underwater. A diver must align this time with a pre-dive plan, track it during a dive and analyse it after a dive. Time and decompression are related and that’s where a diver and a computer work together to mitigate the risks. - Depth limit – A diver must monitor the depth at all times. Losing the track of time and space in unearthly environment would be inevitable without a computer. Therefore, a

	diver must use the computer to combine depth and time data to successfully calibrate their decompression and diving procedures. - Ascent/descent limit – Every activity underwater must be conducted slowly and deliberately. Biggest concerns in diving are associated with fast ascent/descent rates. A human body needs time to release inert gas. Going slowly entails keeping factors under control. The framework proposes, following computer's data regarding time/depth, having the ascent/descent rate of 9-11 meters/minute.
3. Technology outputs and insights	- Dive analysis – Dive computer provides a personalized dive history. It transfers dive data into electronic log, which dispenses diver with a capability of recording smallest details. Every additional dive will accumulate more dive data which will progress the safety and experience of diving. A diver must comprehend and analyse computer's output to further enable enhancement of every diving aspect. - Lessons learned – After analysing dive computer's data, certain insights and conclusions will emerge. A diver then learns how to improve their safety and experience. That is possible only when we purposefully handle dive computer and its data, which will give indications and directions on how to get better, safer and more amused.

Table 3 - The Framework Summary

5.3. Demonstration of the Solution Development

The proposed framework is consisted of rules, policies and guidelines which should be followed in order to decrease the risk of decompression sickness to a minimum, while taking into account all the practical and safety measures of diving. The framework is relying on the dive computer's operations which are programmed with a variety of decompression models. Those models are Reduce gradient bubble model and AI wireless transmitting system which measures gas pressure.

Before diving into hypothesis, one must ensure that they are fit to immerse underwater. No technology or practice can allow the diver to achieve the minimum of safety standards, without claiming the necessary knowledge, skillset and training needed. It must be clear that a diving computer can never completely eliminate the risk of decompression sickness and related adversaries. A dive computer cannot take into account a diver's physical or mental conditions, which may vary daily. As mentioned throughout the paper, a computer is not there to facilitate diving practices for a diver, but rather to assist them in conducting those practices safer, more efficient and more enjoyable. Furthermore, the first and foremost condition for a diver, regardless of diving nature and purposes, is to go through thorough medical check before commencing any kind of dive. Also, divers must assess their own physical condition before and after every dive. Imbert et al. (2019) states that 42% of people who suffered from DCS show symptoms within the first hour after a dive, 83% of them show symptoms within the first eight hours, and 98% of them show symptoms within the 24 hours after dive. Thus, it is crucial that divers dedicate time and effort to checking the state of their surrounding and their own state before and after diving.

Dive computer can be no good to a diver that doesn't know how to use it or how to read the information provided by the computer. The dive computer will process all the calculations in fly time and it will conduct all the necessary operations, from which it will display all the results and stats to its owner. However, a limited diver with no training nor certification will not be able to properly understand the displayed data and they will be prone to a misconduct. No computer can replace dive training. All participants in the diving industry should remember that only adequate training can ensure the safe dive.

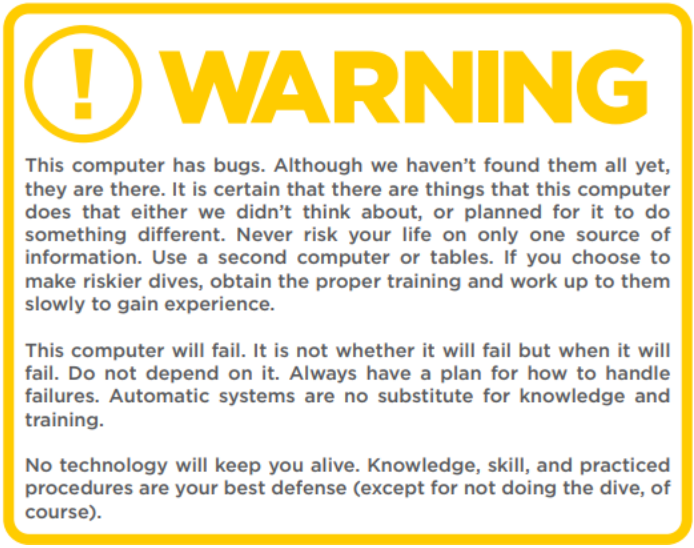

Figure 8 - Disclaimer from one of the dive computer manufacturers (DAN, 2022)

Divers must be aware at all time that, while diving, they are involved with procedures that may result in serious injury or death. Lack of alertness has been known to cause major issues while diving. Therefore, lack of knowledge can and will be detrimental for a diver.

All computers experience failures. There is always a possibility that a dive computer suddenly fails to provide accurate information during the dive. Only a trained diver should use a dive computer. Insufficient training for any kind of diving may cause a diver to commit avoidable errors. That is where a diver training comes into play. Appropriate use and handling of gas mixtures, proper decompression theories and practices, and confidence to read and interpret dive tables are essential in order to safely facilitate the dive.

There are notable reasons why diving is considered as a safe sport nowadays. It is a direct result of a great deal of time and effort invested into the research of underwater activities and conditions, in addition with diving training and enhancements in diving technology.

So, learning to perceive, use and interpret the computer's data, even without the computer, is of crucial importance. One shall ask – how would somebody be able to use the computer's data without the very computer? The answer is simple. Dive tables – a models on which the computer's algorithms are relying upon. One of the most remarkable inventions in the diving history, dive tables are the essential knowledge for any diver who wishes to achieve high levels of both safety and underwater experience.

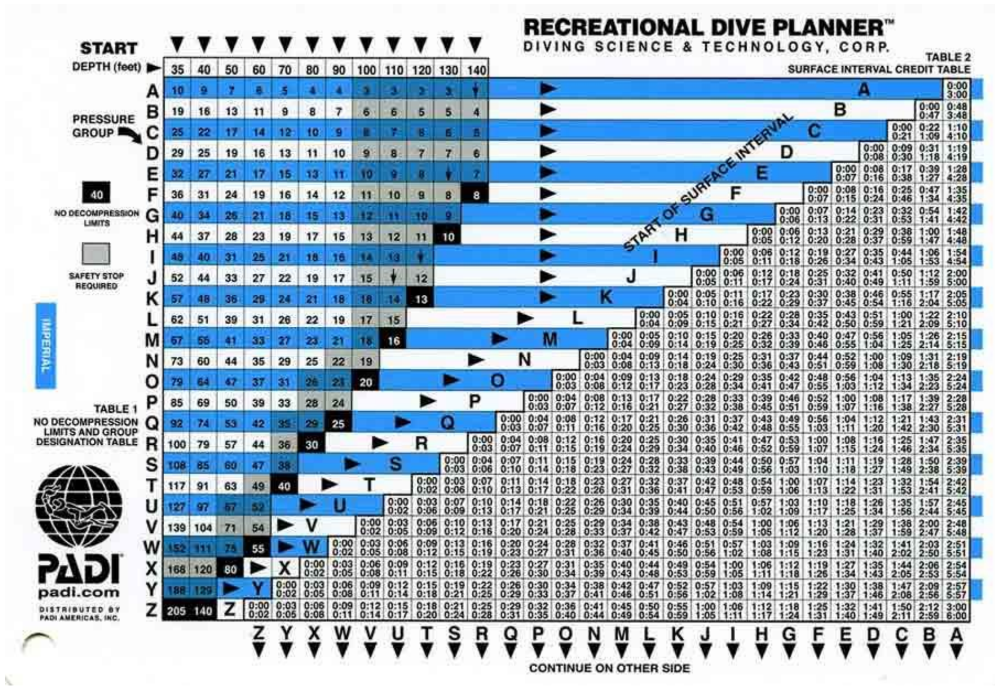

Figure 9 - Professional Association of Diving Instructors dive table for recreational diving (PADI, 2022)

A dive table, such as the one shown in the figure above, categorizes depth and bottom time (bottom time = time to reach certain depth + time spent at certain depth + time to reach surface). So, by looking at such table, a diver should be able to calculate how long they can safely stay at a given depth, while taking in regards to whether if it's an initial or a repetitive dive. But, the thing is that dive tables do not tell you how much residual nitrogen you have in your body tissues. That is the biggest misconception of divers towards dive tables.

Therefore, when reading the table or computer, and applying the reading conclusions, a diver should never reach the limits of what table or computer is proposing. As we have mentioned, every system is prone to error – thus we cannot solely rely on that.

A dive computer will assist a diver in determining their safe decompression procedures. However, what should a diver do in case of (sub)consciously disrespecting decompression procedures and limits? It is relatively easy to commit a mistake underwater, to get distracted, or to get impacted by factors beyond our control. Divers must always plan their dive and dive their plan, but they also must be ready to react accordingly in case of adverse events. After thoroughly studying a variety of dive tables, decompression models, dive computer algorithms, we have come up with two comprehensive guidelines:

1. If a no-decompression limit is exceeded by less than 5 minutes – a diver has to conduct an 8 minutes safety stop at a depth of 5 meters and remain at the surface at least 6 hours before diving again

2. If a no-decompression limit is exceeded by more than 5 minutes – a diver has to conduct at least 15 minutes safety stop at a depth of 5 meters and remain at the surface for 24 hours before diving again

In both cases, a diver should seek a medical attention as soon as possible after they reach the surface. In the meantime, a diver must be administered with a 100% medical oxygen. The framework proposes that every dive centre/boat/organization shall have medical oxygen ready for use at any given moment.

Additional complementary guidelines which we will include in the framework are:

- Dive schedule – abbreviated plan regarding the dive depths and dive times – must be present at each dive and thoroughly inspected;
- Maximum dive time – maximum allowable dive time while staying within the no-decompression limits;
- Decompression safety stop – a precautionary stop, regardless of computer data and whether one reached out of decompression limits, at five meters for three minutes;
- Surface interval time – when diving is repetitive, SIT is the time spent on the surface between two dives. Dive computer will provide the information on how long the SIT should be. We recommend it to be for at least one hour;
- Ascend rate – one should not ascent fast, dive medicine concurs that fast underwater practices ensure catastrophic consequences;
- Decompression control – one must avoid dives that are getting close to the no-decompression limits. A smallest mistake can cost somebody a life!

A dive computer should offer a diver a certain freedom and possibility of user-customizable liberalism/conservatism setting. With that being said, we strongly recommend to follow more conservative algorithm setting, rather than staying away from the limits shown with more liberal setting. Additional conservatism is reassuring – and also rewarding as divers get to spend more time underwater!

We must remember that decompression algorithms are mathematical models intended to predict the outcome of complex physiological processes (Pollock, 2015). They almost certainly do not capture 100% truthful data, but they actually don't need to. All they need to do is to produce a sufficient pattern frequently enough to be accepted.

Learning about the available options is an important strategy in managing risk. The thoughtful and well-informed diver knows far more about conditions that may affect real-time risk during a dive than any dive computers do (Baker, 2019). This will help ensure the positive outcomes that every diver expects.

6. CONCLUSIONS

6.1. FUTURE WORK

It can seem unbelievable that diving and underwater environment have not been scientifically and technologically researched as much as other areas. The fact, mentioned in the chapter concerned with challenges of literature review, that only 0.05% of ocean has been mapped appear to be incredible. What does this mean? This means that there are 360 340 365 km^2 of area, completely unknown to human. How can diving technology contribute in discovering some of that area?

Kuch et al. (2012) develop a dive computer prototype which would be able to conduct seabed mapping and underwater navigation. The dive computer had integrated flow sensors, whose data was retrieved on surface in real-time, which illustrated diver's position in 3D. However, the project was abolished due to the lack of hardware, processing and financial power.

Now, we can just imagine how much scientific advance the humankind would experience if we are able to seamlessly explore 71% of our planet. Certainly, this has to present an opportunity and a goal for future research for various reasons, but mainly due to the wellness of people and the planet.

Ling et al. (2022) have been developing a dive computer which relies on machine learning techniques. The dive computer would serve the purpose and massively contribute when it comes to safety and emergency purposes. It is consisted out of detectors for monitoring diver's conditions, combined Automatic Identification System (AIS) and Global Positioning System (GPS) used for locating the diver, Bluetooth communication used for detecting safety range and a machine learning model which monitors the health status of diver.

It has been noted throughout this paper that probably the biggest downside of decompression algorithms is that they do not take individual characteristics into consideration. In fact, they are just theoretical models. The potential lies in the emerging technologies, such as machine learning, where the model will consider one's dive history. Contemplating dive history, a dive computer which relies on machine learning would recommend a diver a personalized course of action (real-time dive plan), where the computer is monitoring diver's gas intake and bubble solution in their body.

Modern bubble models that conduct the pertinent bubble mechanics are too complex to be managed by the limited processing power of a traditional dive computer microprocessor.

Certain potential is hled in the advancements in a decompression theories. Use of nanotechnology through which we would manage to monitor and even fight nitrogen in our bloodstream. Nanotechnology such as molecular assembler, which could provide some sort of edible nanobots that flows through human body and prevents forming bubbles and enables nitrogen to leave our body faster and smoother.

Lang and Brubakk (2009) discussed the future of diving and what new technologies divers will use. They concluded that divers will have benefits from monitoring technology integrated into the algorithm. Several possible features were elaborated:

- Heart rate monitoring – workload-related nitrogen calculations to monitor how the body responds to the underwater environment
- Skin temperature measurements – implementation of vasoconstriction in a decompression model
- Oxygen saturation measurements – managing the risk of oxygen depletion
- Inert gas bubble detection – developing an integration monitoring decompression stress that provides feedback loop into the decompression models **during** a dive

6.2. Limitations

This paper has been solely focused on theoretical applications rather than practical, due to the myriad of possibilities involved with multiple aspects concerning this work. Knowledge summarized in this work is rigid for the practical application, but it hasn't been tested or experimented to prove that. The framework focuses on the technological aspect of safety and experience while diving. Therefore, other aspects were not taken into consideration when constructing the framework.

Major limitation for this work has been the lack of research in the field of scuba diving and its related fields. As stated earlier in the paper, that scuba diving is actually a rather young niche, but it should not be viewed in isolation and it must be contextualized. That lack of contextualization in scientific research has been causing the lowered standards in scuba diving, which must not happen in order to fulfil the maximum level of safety.

6.3. Final Words

It is fascinating to see how far the humankind has gone underwater due to the technology advancements. As mentioned in the very beginning of this paper, from using tortoise shells as diving goggles, nowadays we mostly rely on technology to keep us safe and amused while being underwater. However, we can conclude that, no matter how advanced, the technology is there just to briefly assist divers in attaining safety and amusement. The sole responsibility of having a safe dive is on divers themselves.

Therefore, the ultimate aim of the framework developed throughout is to provide a hindsight where there must be a sufficient amount of knowledge, skills and confidence to use technology underwater. We have proven multiple times that technology by itself cannot conduct safe underwater practices and policies. Rather, a diver must be medically fit, properly trained and certified, sufficiently knowledgeable, decently confident and continuously attending in diving research in order to attain continuous safety and peak experience.

This paper has contributed to manifestation of the utility and essence of technology in scuba diving. For both the diving community and community not closely related to the sport, it can be clearly understood that humans are not designed to spend substantial periods underwater. We can be certain that without technology, we wouldn't be able to go as long and deep as today.

The framework is validated through several implications:

- The framework is consistent with prior research and practices
- The framework is maximally clarified for the mental model
- The framework logic is manageable
- The framework is fully compliant with decompression theories
- The framework provides a viable risk mitigation in comparison with hazardous and adverse diving profiles
- The framework offers a solution which is easily implemented

85% out of 169 diving-related deaths that happened in 2019, mentioned in the beginning of this paper, happened due to the problems indicated throughout the paper. We have to imagine if that was avoidable in case if there had been such framework which would provide safety countermeasures. I would like to dedicate this research to all of the people who unfortunately died while diving, hoping that this framework can be a reason to avoid adverse events in diving.

We can conclude that the research questions are answered by ensuring that dive computer is not affected by environmental hazards through high-standard guidelines on how to use technology in scuba diving. Dive analysis provide a certainty that dive computer's data is valid and useful for future research. We made it sure to mitigate the risks of technology malfunction and human error by way of instructing strict safety and health protocols (even in the case of uncertain errors). All these criteria will supply a ground for achieving peak experience in scuba diving.

Dive safe and dive often.

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