OPTIMAL BREATHING GAS MIXTURE IN PROFESSIONAL DIVING WITH MULTIPLE SUPPLIES

(PROFESYONEL DALICILIKTA BİRDEN FAZLA TEDARİK İLE SOLUMA GAZI KARIŞIMI ENİYİLEMESİ)

by

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Thesis

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

in

INDUSTRIAL ENGINEERING

in the

GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

of

GALATASARAY UNIVERSITY

July 2021

ACKNOWLEDGEMENTS

I would like to thank Dr. Orhan İlker Başaran for his extraordinary support in this thesis process. The completion of this study could not have been possible without the expertise of him.

I would also like to thank Ayşe Ece Yürekli for the support I have received during this process.

June 2021
Mert Ünal

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LIST OF SYMBOLS

kPa : Kilopascal
ULC : Ultrasound Lung Comets
EVLW : Extravascular Lung Water
SCUBA : Self-Contained Underwater Breathing Apparatus
PAP : Pulmonary Artery Pressure
TLCO : Transport Factor for Carbon Monoxide
ADHD : Adult Attention-Deficit/Hyperactivity Disorder
DCS : Decompression Sickness
CNS : Central Nervous System
EAN : Enriched Air Nitrox
Atm : The Standard Atmosphere
MOD : Maximum Operational Depth
GA : Genetic Algorithm

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ABSTRACT

Men have gone into the ocean to gather food since the beginning of human life, but it is hard to distinguish the precise date or origin of diving. We know from fossils that as long as 4,500 years ago, Mesopotamian people participated in diving as a means of trade, typically gathering pearl oysters. Professional diving activities have expanded dramatically as a result of technology improvements in the last century. Professional diving is when divers are compensated for their efforts. Professional diving is divided into various disciplines, the most well-known of which being commercial diving. Commercial diving is an application of professional diving in which the diver does underwater work for industrial, construction, engineering, maintenance, or other commercial objectives that are comparable to work performed outside of the water, with the diving being secondary to the activity. The goal of this research is to optimize the breathing gas combination while lowering diving expenses and maintaining the safety of the divers.

The cost of the diver and the cost of breathing gas are the two primary expenses examined in this study. The cost of a diver is considered to be hourly. Because the breathing gas is considered to be made by enriching the air with oxygen, the sole expense is the addition of pure oxygen to the breathing gas to make the Nitrox combination. Both the diver and breathing gas costs will increase as the dive time increases. The dive period is separated into two parts, the first of which is the dive itself, during which the professional diver performs several duties. The diver should begin the ascent procedure whenever all or part of the duties has been performed. The diver does not do any tasks at this period and might be deemed idle. The goal is to cut down on the diver's idle time. To do so, the proportion of Nitrogen in the breathing gas should be reduced while the percentage of Oxygen in the breathing gas should be raised, resulting in an increase in the cost of breathing gas.

Two hypothetical problems are solved to illustrate the proposed model. The first problem is considered as a single dive and the second problem is considered as a repetitive dive. In each problem single gas and multiple gas models have been used and each numerical example is solved with MATLAB using the Genetic Algorithm of Global Optimization Toolbox. To begin, the method generates a random start population. After then, the algorithm generates a series of new populations. The program creates the future population using the individuals in the current generation at each step. The algorithm stops if the terminating conditions have been reached. The results show that the diver needs less time for decompression hence the idle time decreases. On the other hand, the gas cost increases gradually as the number of decompression gas increase. This is due to the fact that additional gases are richer with oxygen which increases the mixture cost. In total the cost decreases, but the most significant decrease happens with the addition of the second gas. The methods presented in this study are strictly theoretical, and divers should always be properly trained and certified.

RÉSUMÉ

Les hommes sont allés dans l'océan pour ramasser de la nourriture depuis le début de la vie humaine, mais il est difficile de distinguer la date ou l'origine précise de la plongée. Nous savons par les fossiles qu'il y a déjà 4500 ans, les Mésopotamiens participaient à la plongée comme moyen de commerce, en récoltant généralement des huîtres perlières. Avec les progrès technologiques du siècle dernier, les activités de plongée professionnelle ont considérablement augmenté. La plongée professionnelle est la plongée où les plongeurs sont payés pour leur travail. Il existe plusieurs branches de la plongée professionnelle, dont la plus connue est la plongée commerciale. La plongée commerciale peut être considérée comme une application de la plongée professionnelle lorsque le plongeur s'engage dans des travaux sous-marins à des fins industrielles, de construction, d'ingénierie, de maintenance ou à d'autres fins commerciales similaires au travail effectué hors de l'eau, et où la plongée est généralement secondaire au travail. Dans cette étude, nous nous concentrons sur l'optimisation du mélange de gaz respiratoire en minimisant les coûts de plongée tout en assurant la sécurité des plongeurs.

Les principaux coûts pris en compte dans cette étude sont le coût du plongeur et le coût du gaz respiratoire. Le coût du plongeur est supposé être horaire. Le gaz respiratoire est supposé être préparé en enrichissant l'air avec de l'oxygène, donc le seul coût est l'oxygène pur ajouté au gaz respiratoire afin d'obtenir le mélange Nitrox. Au fur et à mesure que le temps de plongée augmente, le coût du plongeur et le coût du gaz respiratoire augmenteront. Le temps de plongée peut être divisé en deux étapes, la première étape est la plongée elle-même au cours de laquelle le plongeur professionnel effectue certaines tâches. Une fois les tâches entièrement ou partiellement terminées, le plongeur doit commencer la procédure de remontée. Lors de cette seconde étape, le plongeur n'effectue aucune tâche et peut être considéré comme inactif. L'objectif est de

diminuer le temps d'inactivité du plongeur. Pour y parvenir, la fraction d'azote dans le gaz respiratoire doit être abaissée et la fraction d'oxygène du gaz respiratoire doit être augmentée, ce qui augmentera à son tour le coût du gaz respiratoire.

Deux problèmes hypothétiques sont résolus pour illustrer le modèle proposé. Le premier problème est considéré comme une plongée unique et le deuxième problème est considéré comme une plongée à répétition. Dans chaque problème, des modèles à gaz unique et à gaz multiples ont été utilisés et chaque exemple numérique est résolu avec MATLAB. L'algorithme commence par créer une population initiale aléatoire. L'algorithme crée alors une séquence de nouvelles populations. À chaque étape, l'algorithme utilise les individus de la génération actuelle pour créer la population suivante. L'algorithme s'arrête si les conditions de terminaison sont atteintes. Les résultats montrent que le plongeur a besoin de moins de temps pour la décompression donc le temps d'inactivité diminue. D'autre part, le coût du gaz augmente au fur et à mesure que le nombre de gaz de décompression augmente. Ceci est dû au fait que les gaz supplémentaires sont plus riches en oxygène ce qui augmente le coût du mélange. Au total, le coût diminue, mais la diminution la plus importante se produit avec l'ajout du deuxième gaz. Les méthodes proposées dans cet article sont purement théoriques et les plongeurs doivent toujours avoir une formation et des certificats appropriés.

ÖZET

Yüzyıllardır insanlar nefes tutarak dalmayı dünyanın çeşitli yerlerinde uygulamışlardır. Fosillerden bilindiği kadarı ile yaklaşık 4,500 sene önce insan okyanus dipleri ile tanışmış, aklı ve keşfetme arzusu ile bugünkü duruma gelmiştir. Suyun altını keşfetmek belki de her insanın düşlerini süslemiştir. Avlanma, keşfetme, tekneleri tamir etme veya ele geçirme istekleri, hazineler bulma hayalleri su altında uzun süre kalabilme isteğini arttırmıştır. Son yüzyılda yaşanan teknolojik gelişmelerle profesyonel dalış faaliyetleri önemli ölçüde artmıştır. Profesyonel dalış, dalgıçlara çalışmaları için ödeme yapılan dalıştır. Profesyonel dalışın en çok bilinen branşı sanayi dalgıçlığıdır. Sanayi dalgıçlığı, dalgıcın su dışında yapılan işlere benzer endüstriyel, inşaat, mühendislik, bakım veya diğer ticari amaçlarla su altı çalışmalarında yer aldığı bir profesyonel dalış uygulaması olarak düşünülebilir. Bu çalışmada dalış maliyetlerini minimuma indirirken solunan gaz karışımının optimize edilmesi planlanmıştır.

Bu çalışmada ele alınan ana maliyetler dalgıç maliyeti ve solunum gazı maliyetidir. Dalgıç maliyetinin saatlik olduğu varsayılmıştır. Solunum gazının havanın oksijen ile zenginleştirilerek hazırlandığı varsayılır. Bu nedenle tek maliyet, Nitrox karışımını elde etmek için solunum gazına eklenen saf oksijen maliyetidir. Dalış süresi arttıkça hem dalgıç maliyeti hem de solunum gazı maliyeti artacaktır. Dalış süresi iki aşamaya ayrılabilir, ilk aşama profesyonel dalgıcın belirli görevleri gerçekleştirdiği dalışın kendisidir. Görevler tamamen veya kısmen tamamlandığında, dalgıç çıkış prosedürüne başlamalıdır. Bu ikinci aşamada dalgıç herhangi bir görev yapmaz ve boşta sayılır. Amaç dalgıcın boşta kalma süresini azaltmaktır. Bunu başarmak için, solunum gazındaki azot oranı düşürülmelidir. Ancak azot oranını azaltmak için, solunum gazının oksijen oranını arttırılmalıdır, bu da solunum gazı maliyetini artıracaktır. Bu çalışmanın amacı, toplam maliyetleri minimize ederken bu iki maliyet arasındaki dengeyi bulmaktır.

Önerilen modeli göstermek için iki varsayımsal problem çözülmüştür. İlk problem tek dalış, ikinci problem tekrarlı dalış olarak kabul edilir. Her problemde tek gaz ve çoklu gaz modelleri kullanılmış ve her sayısal örnek, Genetik Algoritması kullanılarak MATLAB ile çözülmüştür. Algoritma, rastgele bir başlangıç popülasyonu oluşturarak başlar ve daha sonra bir dizi yeni popülasyon oluşturur. Her adımda, algoritma bir sonraki popülasyonu oluşturmak için mevcut nesildeki bireyleri kullanır. Sonlandırma koşullarına ulaşıldığında algoritma durur. Sonuçlar, dalgıcın dekompresyon için daha az zamana ihtiyaç duyduğunu, dolayısıyla boşta kalma süresinin azaldığını göstermektedir. Öte yandan, dekompresyon gazı sayısı arttıkça gaz maliyeti kademeli olarak artar. Bunun nedeni, ilave gazların oksijence daha zengin olması ve bu da karışım maliyetini artırmasıdır. Toplamda maliyet düşer, ancak en önemli düşüş ikinci gazın eklenmesiyle olur. Bu yazıda önerilen yöntemler tamamen teoriktir ve dalgıçlar her zaman uygun eğitim ve sertifikalara sahip olmalıdır.

1. INTRODUCTION

Men have gone into the ocean to gather food since the beginning of human life, but it is hard to distinguish the precise date or origin of diving. We know from fossils that as long as 4,500 years ago, Mesopotamian people participated in diving as a means of trade, typically gathering pearl oysters. The Greeks of Thebes also had a flourishing pearl diving industry in the third millennium before Christ, which was followed by the Chinese. As Homer mentioned, sponge fisherman tried to dive to depths of 100 feet (30 m) or more by carrying a heavy rock as early as 1000 B.C. The most famous divers of antiquity were the Greeks Seyllias of Scione and his daughter Cyana. A popular practice in the world was to collect pearl oysters and fish through diving. From the Ama divers of Japan and Korea to the Maya of Central America and the Yahgan Indians of the Cape Horn area, freediving has a long and illustrious history an Egyptian named Ahsan-ul-Ghawasin, also known as Issa, is credited with the invention of first diving apparatus. In 1772, a machine was produced by Sieur Freminet. John and William Braithwaite developed and produced an upgraded version of the helmet in 1786 and another version of the helmet improved by a German guy named Karl Heinrich Klingert, in 1787. In 1825, the English inventor, William James refined the self-contained device. One of the earliest successful recovery operations with a one-person diving bell took occurred in 1531 in Lake Nemi in Rome. A thesis on diving bells was written by a scholar called George Sinclair in 1669. Sir William Phips, a famed salvor, used a bell to collect approximately $1 million in treasure from the wreck of the Spanish galleon La Nuestra Senora de Almiranta in the West Indies in 1685, based on his beliefs. At around the same time as Sinclair was writing about diving bells, a contemporary named Sir Robert Boyle was making important insights regarding the behavior of gases under pressure. Using Boyle's study, Abbe Hautefeuille published The Art of Breathing Underwater in 1681, establishing for the first time that "man cannot breathe air at normal atmospheric pressure while he is himself beneath water at depth." The more advanced diving bells were developed by Sir Edmund and John Lethbridge (Brylske, 2012).

William James is probably the designer of the first workable self-contained diving system. This can be found in the writings of both Renaissance scientists Leonardo da Vinci and Giovanni Borelli. Although his design dates back to 1825, there is no confirmation that it has ever been used. On the other side of the Atlantic, the first practical machine was finally invented. The first practical self-contained diving system was produced and used by an American, Charles Condert, in 1831. Condert had to carry a 200-pound (90 kg) ballast to counteract the machine's enormous positive buoyancy. His method worked, and he is said to have dived in the East River to a depth of roughly 20 feet (6 meters). T. Cato McKeen, another American, improved Condert's design by adding a huge back-mounted air reservoir. Benoit Rouquayrol and Auguste Denayrouze undoubtedly constructed the most effective self-contained design of the 18th century. They invented the Aerophore in 1865. This apparatus was similar to other designs except the regulator to control the air delivery. Thus, by the 1870s, attention turned to the development of an oxygen system that could clean and recirculate the breathing gas, a system we call a rebreather system today. The Frenchman Pierre Aimable De Saint Simon Sicard is also credited with the first practical design for his patent in 1849. German biologist Theodor Schwann's patent was close to Sicard’s design. Englishman Henry Fleuss invented an apparatus in 1878 consisting of a rubberized cloth hood, a breathing bag and a copper cylinder containing oxygen compressed into 30 atmospheres (440 psi). The machine required intermittent recharging from the oxygen source, as the diver rebreathed his expired air. Fleuss' device was used in one of the most impressive commercial diving activities in history. In 1900, Louis Bouton, the inventor and early underwater photographer, returned to an air-based style. Finally, the self-contained diver was starting to look like his modern equivalent (Brylske, 2012).

First contributions to decompression theory were made by one of the greatest scientists of 17th century, Sir Robert Boyle. Another German scientist Otto Von Guericke invented the first vacuum pump which could remove or compress air in the 17th century. By the steam engine, the Industrial Revolution accelerated. Coal was feeding the engines so it was necessary get more. It meant to dig deeper. So, the French thought that pumps could play a key role. In Chalons, France, they built the world's first pressurized mine in 1841. Soon after, the first cases of a mysterious disease that came to be known as decompression sickness were identified. Doctors at the time reported that the afflicted miners showed symptoms of “pain in the ears and joint pains." The problem began to be studied by other scientist, and two French physicians named Pol and Wattelle described the nature of the disorder in 1854. "The danger, “they said,” does not lie in entering a shaft containing compressed-air; or in remaining there a longer or shorter time; decompression alone is dangerous." They realized first that the problem was about someone going to high pressure level and then to the lower pressure level. By 1857, another researcher named Felix Hoppe-Seyler concluded that it has to be something about bubbles. Paul Bert, French physiologist, analyzed the gas bubbles in decompression experiments. He found that the gas bubbles mostly contained nitrogen. He concluded that the bubbles caused the sickness as Hoppe-Seyler. In 1879, he described his theory in his book, “La Pression Barometrique.” Bert proposed that the underwater workers should come slowly to the surface pressure, allowing nitrogen gas to escape before it formed bubbles. Bert deduced that, as the bubbles were composed mainly of nitrogen, divers should breathe pure oxygen to expel the nitrogen from the body. During his study, Bert made another landmark discovery. He was the first person to describe the toxic effects of high-pressure oxygen. Bert’s techniques were applied during the construction of the tunnel connecting New York with Jersey City. There was a marked decrease in the number of decompression sickness cases, and a reduction in the number of fatalities (Brylske, 2012).

Haldane recognized that the production of nitrogen bubbles was the possible source of decompression sickness and the bubbles formed upon ascent. He deduced that a person could tolerate a certain degree of excess nitrogen pressure without bubble formation. The problem was determining exactly what this "certain" amount was, and how the pressure could be reduced in a predictable way to avoid bubble formation. Haldane needed to study in more controlled ways. Luckily, he had access to an experimental hyperbaric chamber. Even though he could get willing volunteers, Haldane realized that the preliminary tests would be too uncertain and potentially dangerous to use human subjects. So, he searched for the animals as mice, rats, rabbits. But small animals were useless because of their body size. It was not too easy to detect signs of joint pain in a rat or a rabbit. Finally, he used goats. He deduced that the human body could tolerate pressure change with a factor of 2:1. Once the 2:1 ratio was achieved, the remaining portion of the ascent must proceed much more slowly. It is known as “stage decompression.” The phenomenon was complex because all parts of body don’t absorb the same amount of gas. It varies due to the amount of blood flow to the tissue and the density of the tissue. To solve the dilemma, Haldane formulated an approach which will be the origin of the multi-tissue model of decompression. Another of the observations made by Haldane was that both gas absorption and gas disposal happened at an accelerated rate. He explained it by using a common form of mathematical description: a half-life or half-time. Haldane could then calculate the time and depth from which a diver could ascend without exceeding the permissible nitrogen pressure in either compartment using a method of measuring nitrogen pressures in any of its compartments. If the diver exceeded the maximum compartment pressure, then a decompression stop was necessary. Stopping the ascent at predetermined intervals allowed decreasing of nitrogen pressure in the diver’s tissues. Once the stop was completed, the compartment pressures were reduced and the diver could then ascend to the surface. Although Haldane made an incalculable contribution to the field of decompression, his system was far from perfect. His system was not suited for making more than one time a day. In the early 1930s Charles Shilling showed that no current model could predict decompression for extended deep dives. In 1935, another researcher J.A. Hawkings analyzed Shilling’s data and he concluded that Haldane’s 2:1 ratio was not consistent for all compartments and rather than a single ratio, each compartment should have its own surfacing ratio. In 1937, O.D. Yarbrough improved Hawkins’ work. He concluded that the five- and 10-minute compartments could tolerate such a large reduction in pressure that they could be ignored. Based on Yarbrough's conclusions, the Navy published a revised set of tables that same year. Eliminating the fast five- and 10-minute compartments, Yarbrough's tables included only the 20-, 40- and 75-minute compartments. In addition, each compartment was given an individual surfacing ratio. Still Haldane’s and Yarbrough’s tables were not perfect because of being unable to handle decompression requirements for prolonged deep dives (Brylske, 2012).

A researcher named O.E. Van Der Aue was searching ways to enable surface decompression. Surface decompression is transfer of the diver to a decompression chamber right after the dive. This gives advantages in both safety and comfort. As a result of diver's decompression sickness Van Der Aue found that Yarbrough's tables were inadequate. By the early 1950s the Navy concluded that they should revise their tables to improve their safety and reliability. M. Des Granges and J.V. Dwyer were assigned to this task. From their research they concluded that as the depth and time of a dive increase, so must the depth of the decompression stop. They also restored to the decompression model the fast five and 10 minute compartments. They added a much longer half-time compartment (120 minutes). Scuba also influenced the decision to revise tables. Because of all diving was surface-supplied, limited air supply had never been a problem. This wasn't the case with scuba. The very limited supply of air in the tank would sometimes require the diver to change tanks. To exit and re-enter required a nitrogen removal. This led to the development of methods and terms. So, to solve this problem, a new table had to be made. The new table allowed the diver to calculate how much nitrogen was eliminated between dives. After publishing the tables, they adopted by recreational diving community and they became the standard for decompression procedures. The next refinement was about dive computers. Robert Workman introduced the concept of M-values in 1965. This simplified the complexity of comparting various surfacing ratios. Workman's idea was to define the maximum amount of nitrogen allowed in any compartment not as a ratio, but as an expression of pressure; specifically, pressure in feet of seawater (fsw). His method of computing decompression status was simpler than continually comparing ratios. Many decompression models are still using Workman's method (Brylske, 2012).

Gas bubbles form was area of debate. Professor Haldane believed that if a tissue's saturation limit was exceeded, bubble formation became essentially spontaneous. Albert Behnke, U.S. Naval researcher, challenged this concept in 1942. Behnke deduced that small harmless bubbles probably formed before reaching a size that caused DCS. These small bubbles are called as silent bubbles. Contrary to what Haldane thought bubble formation was not spontaneous. Instead, bubbles formed in a gradual process, developing first from tiny gas micronuclei or "gas seeds." With the technology advancements, silent bubbles hypothesis confirmed. In 1958 two researchers, Shigeo Satomura and Ziro Kaneko, developed the Doppler flowmeter, which used ultrasonic waves to monitor blood. In 1968, two other researchers, Merrill Spencer and S.D. Campbell, were the first to detect gas bubbles in the circulation of sheep decompressed from 200 feet (61 m) for an hour. Many scientists believed that Haldane's methods are fundamentally wrong. Other researchers take a more moderate approach and say that Haldane's theory works only under certain circumstances; or that his theory explains only part of the picture. In the 1960s, D.J. Kidd and R.A. Stubbs came out with an improvement on Haldane's ideas. To solve the decompression dilemma, they decided to approach the problem in a very different way. In the Haldenean model, he believed that each compartment does not have any interaction with the others. Kidd and Stubbs concluded that it probably wasn't reasonable for the tissues of our body to act independently of one another. They developed the first decompression model that considered the interaction among compartments. They produced dive computers based on this premise between 1962 and 1965 (Brylske, 2012).

Professional diving is diving where the divers are paid for their work. Because diving is an inherently dangerous vocation in which the diver works as part of a team, operations are frequently governed by laws and codes of practice. Commercial diving and its specialized applications, offshore diving, onshore diving, inshore civil engineering diving, marine salvage diving, hazmat diving, and ships husbandry diving are probably the most well-known disciplines of professional diving. Scientific study, maritime archaeology, fishing and aquaculture, public service, law enforcement, military duty, and diver training are all the other applications. The most prevalent form of commercial diver is an offshore diver. They work for firms that have offshore activities, such as oil and gas corporations. Their role is to assist in the exploration, maintenance, and construction of undersea infrastructure utilized in oil and gas extraction. Engineering tasks are more important to onshore divers. Qualified divers generally operate in freshwater environments such as rivers, lakes, and even dams. Divers assist in the surveying and construction of bridges and dams. Offshore divers' military equivalents are naval divers. They are, however, not the same as military divers. Ships and boats are inspected and cleaned by naval divers. They might also help with underwater wreckage inspection and the rescue of planes and ships that have crashed. Underwater species are studied by scientific divers. These scuba divers are also researchers. Because they gather undersea samples for research projects, they frequently collaborate with government organizations and universities.

The pressure under the water is much higher than the normal level. For this reason, the working environment under water is different from the working environment on the surface. Divers should be aware of this and act according to the diving rules. If the rules are not followed, some diseases can be seen. The most common of these are oxygen toxicity, nitrogen narcosis, decompression sickness. Breathing oxygen at a high partial pressure for long periods of time may be damaging to the body; oxygen becomes toxic when there are too many molecules in our cells. The diver could also be face by nitrogen narcosis. The partial pressure of nitrogen increases as the total gas pressure rises with increasing dive depth, and more nitrogen is dissolved in the blood. Decompression sickness is also another disease caused by nitrogen. More Nitrogen is dissolved in various human tissues when the diver spends more time underwater at increased ambient pressure. To prevent these diseases, the dive profile should be well adjusted.

To estimate tissue loads and identify safe ascending protocols, several models have been developed. We utilize Bühlmann's model to compute the diving profile for a particular breathing gas combination of oxygen and air in this research. In this study, different number of gas mixtures with different oxygen percentages has been proposed for different scenarios. Increasing the amount of oxygen in the gas mixture increases the gas cost and shortens the diver's operating time. Consequently, the diver cost is reduced. Divers working in these areas can receive their payments hourly, weekly or monthly. Salaries may vary according to the duration of the work, to the company where the diver works, the region where the work is performed, and the degree of danger of the work. In this study, the diver cost is assumed to be hourly.

Optimization of the breathing gas mixture is an important problem in commercial diving while keeping costs to a minimum. Therefore, we have carried out an optimization study aimed at this. Our objective is to find the balance between to these two variables, the diver’s cost, gas cost. To demonstrate the proposed model, two hypothetical problems are solved. The first problem is confined to a single dive, whereas the second is regarded as a series of dives. In each scenario, it has been considered that divers dive with both a single gas mixture and more than one gas mixture. Each numerical example is solved with MATLAB using the Genetic Algorithm. Genetic algorithms produce a set of solutions consisting of different solutions instead of producing a single solution to problems. Thus, many solutions are evaluated at the same time in the search space, and as a result, the probability of reaching a global solution increases. The solutions in the solution set are completely independent of each other. The evolution process normally begins with a population of randomly produced individuals and proceeds in an iterative manner, with each iteration's population being referred to as a generation. Every individual in the population is evaluated in each generation; the fitness is generally the value of the objective function in the optimization problem being addressed. In our study the fitness (objective) function is the dive cost and the dive cost varies with the percentage of oxygen in the gas mixture. Therefore, the percentage of oxygen becomes the decision variable.

2. LITERATURE REVIEW

Ambient pressure sensitivity has been shown to have short-term physiological consequences. The long-term cardiovascular effects of diving on humans have received less attention. Pathological pulmonary alterations occur after 3-24 hours while inhaling oxygen at partial oxygen pressures (P-O2) between 50 and 300 kPa, depending on the P-O2. This type of damage (also known as pulmonary oxygen toxicity) is common in ventilated patients, but it can also happen to oxygen or mixed gas divers. Hollmann et al. (2013) performed research to demonstrate the pathophysiological impact of breathing oxygen with P-O2 of 50-300 kPa on the respiratory tract. By assessing the occurrence of cardiovascular disease in retired divers to non-divers, Asmul et al. (2017) sought to investigate potential long-term cardiovascular health implications from industrial diving. According to the findings, the incidence of certain cardiovascular symptoms and disorders in male former divers could be higher than in the general population. A professional diving institute conducted another research. Extravascular lung water was measured via chest ultrasonography to identify ultrasonic lung comets (ULC). According to the findings of the study, exercise intensity is a major factor in the increase in EVLW in healthy divers. Other stressors examined, such as water temperature and hyperoxic toxicity, were not shown to be directly associated to the increase in ULC number detected by chest ultrasonography (Boussuges et al., 2017).

For dives deeper than 60 meters, a growing majority of recreational self-contained underwater breathing apparatus (SCUBA) divers use a trimix of oxygen, helium, and nitrogen. SCUBA diving has rarely been related to the occurrence of pulmonary edema, because it's unclear how it impacts EVLW aggregation. Marinovic et al. (2010) investigated the relationship between asymptomatic SCUBA dives and the aggregation of EVLW. Seven divers completed six dives using a compressed gas mixture of oxygen, helium, and nitrogen (trimix), at depths ranging from 55 to 80 meters. According to them, their study was the first to show that asymptomatic SCUBA dives are linked to EVLW aggregation and a rise in pulmonary artery pressure (PAP). When breathing compressed gas mixtures underwater, divers face many possible neurological threats, including nitrogen narcosis, which may impact diver's safety. Using vital flicker fusion frequency (CFFF) as a cortical success measure, various human experiments have specifically shown brain damage due to nitrogen narcosis in divers at 4 ATA. A study has been conducted by Rocco et al. (2019). Sixty experienced divers breathing Air, Trimix, or Heliox were tested on an open water dive to a depth of 6 ATA. Their findings showed a complex network explaining the brain pathways in which nitrogen and oxygen, alone or in combination, generate neuronal excitability or depression in a dose-dependent manner.

Since hydrostatic pressure contributes to air pressure as diving depth increases, the diving atmosphere differs from life at sea level in terms of a higher ambient pressure. Due to Boyle's law, total lung capacity decreases as depth or ambient pressure increases. As a result, the pressure and density of the gas inside the lungs will rise. A retrospective research was conducted on divers who had a scientific activity and had an initial visit and a visit 15 years later at the same medical center. Pulmonary function measurements were conducted using a Jaeger Master Body plethysmograph in the same laboratory with the same operating conditions. Each subject was in charge of his or herself. Student's t-test and Spearman's correlation coefficient were used to analyze the results. The pulmonary function shows a tendency toward both a decline in transport factor for carbon monoxide (TLCO) and a decrease in forced expiratory flow (FEF%25) as the duration of diving activities operation increases (Pougnet et al., 2019). Pougnet et al. (2013) performed another study to assess improvements in lung function after ten years of professional diving. Using a Jaeger Master Body plethysmograph, pulmonary function measurements were conducted in the same laboratory with the same operating conditions. They discovered that as the amount of time spent diving activities increases, the pulmonary function shows a tendency toward both a reduction in TLCO and a bronchial obstruction that extends to larger bronchi. Besides higher ambient pressure, environmental factors are also different from life at sea level such as visibility and temperature. Sometimes these factors could make the dive difficult. Individuals rely largely on tactile performance (perception and manipulation) to execute complicated tasks in a task environment when sight has worsened. When this occurs under hyperbaric conditions, nitrogen narcosis can have an impact on a person's ability to complete certain activities. In the absence of visual access to the test, Meintjes et al. (2014) investigated the impact of nitrogen narcosis on a dynamic neuropsychological task assessing tactile performance at a pressure of 608 kPa (6 ATM abs). Environmental stressors necessitate a dynamic mechanism of psychophysiological adaptation on the part of the experienced diver in order to meet the demands of an intense environment to perform productive and efficient work under water. The role of cognitive and personality characteristics in forecasting underwater success and adaptation has long been a source of debate in diving psychology, and definitive conclusions have not been reached. Colodro-Plaza et al. (2014) used regression methods to test the predictive validity of general mental capacity and personality characteristics in predicting human variations in adaptation to a hostile environment. Individual variations are linked to the likelihood of good adaptation and productive results in competitive diving, according to the results. They undertook another analysis to confirm the importance of individual variations in adaptation to a harsh and aggressive environment. The findings suggest that there are psychological factors that distinguish divers from the general public, those who succeed or fail a diving course, and classes of divers who perform at various ranges of underwater activities. The results reinforce the idea that dispositional traits should be used to identify people who are appropriate for professional diving (Colodro-Plaza et al., 2014).

Adult attention-deficit/hyperactivity disorder (ADHD) is a mental health condition characterized by a number of chronic issues, including trouble paying attention, hyperactivity, and impulsive conduct. Accidents underwater can have serious repercussions, thus ADHD in professional diving might have considerable occupational health and safety issues. A study was carried out on a group of navy divers. The aim was to show the probability of adverse underwater accidents is substantially higher in the ADHD community (van Wijk et al., 2019).

Barotrauma of the middle ear is typical in divers. Facial nerve baroparesis is a relatively uncommon complication. The presence of a dehiscent facial nerve canal can be a risk factor for this complication. Despite the fact that there are a growing number of cases of facial baroparesis in the literature, it is possible that they are also under-reported. It is important to include this in the comparative evaluation when treating dive accidents in order to prevent excessive recompression procedures or adverse effects on a successful diver's career (Marinides & Virgilio, 2019).

Divers must be protected from the cold, particularly in Arctic conditions. The drysuit's insulating gas coating is critical for minimizing heat loss. The technical diving community has long claimed the superiority of argon over air as an insulating gas. Despite the fact that argon is often used, previous research has found no substantial distinctions between the two gases. Argon can be a greater thermal insulating gas than air because of its lower heat conductivity. During the construction of military drysuit diving equipment in Arctic water conditions, an analysis was performed to see whether argon is useful for limiting heat loss in divers. Lundell et al. (2019) conclude that in Arctic water conditions, argon can be preferable to air as a drysuit insulating gas for certain divers. When used as an insulating gas, argon can make diving safer by lowering the risk of fatal diving injuries and workplace hazards in professional diving.

Drowning is the primary cause of death in self-contained underwater breathing apparatus (SCUBA) diving. Altepe et al. (2017) suggested an integrated system with an algorithm that analyzes the intermediate pressure (IP) signal from a SCUBA regulator to detect divers' breathing. A device consisting primarily of two pressure sensors and a low-power microcontroller was developed and configured to record the pressure sensor signals and provide warnings in absence of breathing. An algorithm was created to interpret the signals and classify the diver's inhalation activities.

Diving is one of the domains in which people are exposed to a much new world than they are used to. Any special installations and breathable gas mixtures are used to support life in such an area, depending on the intent of the underwater task and the diving depth to be reached. Diving chambers are hyperbaric chambers that are used to shape, prepare, assess, and, in the worst-case scenario, rescue divers. Hyperbaric processes are ones that take place at pressures that are greater than average (atmospheric pressure). Skilled divers, whether they work in the science, commercial, or military fields, are trained and tested in high-pressure environments on a regular basis. Deep dive techniques necessitate the use of hyperbaric devices such as diving (hyperbaric) chambers in order to complete every operation safely (Degeratu et al., 2016). Alboiu et al. (2017) sought to design a contemporary gas blending system capable of continuous flow mixing, and they discovered a facility that produces breathable mixes for professional diving. The facility is a one-of-a-kind piece of equipment created by the authors to combine two or three gases to generate binary or ternary breathing gas mixtures for hyperbaric operations. The functioning of the apparatus is primarily focused on gas dynamics phenomena, ensuring that pure gases are injected at a constant mass flow rate independent of the pressure at the consumer. The technique is unique in that it allows for the blending of any type of gas, regardless of the ratios of the chemicals that make up the combination.

Underwater diving practices are very important in a variety of ways. Diving technology has advanced significantly since the second half of the twentieth century, but diving still carries considerable risks, especially for experienced divers who operate at great depths, and limited practicability. The use of robotic devices and automated processes will allow for accurate tracking and evaluation of human operators' physiological conditions during their operations, much as it would in other cases where safety is an issue (for example, in the case of dangerous works or in hostile environments). Conte et al. (2014) set out to create an intelligent robotic system capable of semi-automatically supervising the actions of diving teams. A collection of physiological and behavioral parameters will be monitored by such a system. The data will be analyzed online in order to assess the present situation and recreate the progression of the divers' psychophysical conditions during their missions. Sattar and Dudek (2007) developed an algorithm that allows underwater robots to track moving objects, such as human divers, using periodic motion detection. Periodic motion is commonly associated with underwater propulsion, especially human swimmers' kicking. They calculated local amplitude spectra in a video series to find the position of a diver in the robot's field of view. They employed the

Fourier transform to extract responses in image space with varying intensities over time in order to detect different low frequency oscillations that are associated with typical gaits. They merged the gait detector with other tools to minimize false detections when detecting different sites with significant low-frequency energy responses. Shkurti et al. (2017) proposed a robust multi-robot convoying method that relies on the leading agent's visual recognition to allow target following in unstructured 3-D environments. Their approach was built on the concept of tracking-by-detection, which combines effective model-based object detection with image-based bounding box estimation's temporal filtering. Xia et al. (2019) studied on an approach for autonomous underwater robots to visually detect and identify divers. Their method allows an autonomous underwater robot to identify and differentiate between different divers in a visual scene.

3. METHODOLOGY

Weather, water conditions are very important factors for a safety dive. Weather depends on the season and can be determined in advance. After determining the region where you will dive, it is recommended to examine weather conditions about that region. Maybe at the time you plan to dive there will be storm or rain in that area. In addition, knowing the weather in advance ensures that you are suitable and provided for the possible conditions. Tides are sea movements caused by the gravity of the moon. The movement of the sea with the gravity of the moon creates tidal currents. Before the dive while learning about the climate and sea conditions of the region, you should definitely get enough information about the tides. It is known that in some regions, the sea is pulled or moved for kilometers under the tidal effect. Tidal can affect the clarity of the water and can drag divers far away. Visibility under the water also plays an important role for a safety dive. When the sun's rays come to the sea at an angle of less than 48°, most of them are reflected from the surface without entering the water. In such cases, the water will be darkened. Accordingly, between 10.00 and 14.00 hours are the hours when the sea is brightest. Weather conditions and seasonal changes affect the visibility range in various ways depending on each other. For example, rain can increase the particles in the water both directly and with flood water. Additionally the number of the plankton increases significantly with the water temperature increase (Red tide). Bottom structure, waves and water motions, the time of the dive are the other factors affecting underwater visibility. The equipment used also play an important role for a safety dive. Diving mask, drysuit or wetsuit, fins, regulator, dive computer, scuba tank etc., are some of the equipment used in diving. In this study, we focus on the gases inside the dive tube.

Divers are given breathing gas at atmospheric pressure. The oxygen content of the air is 21% and the nitrogen content is 79%. Under high pressures, both gases have unfavorable impacts on human physiology. At sea level, the pressure is around 1 bar. As the diver descends further into the ocean, the ambient pressure rises. According to Henry's rule, "the quantity of gas absorbed by the tissues of the human body increases as pressure increases," which implies that as the diver descends; the amount of maximum absorbed gas on the human body expands. Also, according to Dalton's law, "the concentration of the various components of the gas mix is proportional to their partial pressure in mixes of breathing gases." We may derive from these two principles that lowering the amount of nitrogen in the breathing gas lowers its partial pressure, resulting in less absorbed gas in human tissues under pressure. Enriched Air Nitrox (EAN) is a form of oxygen-enriched gas that is commonly utilized for both recreational and professional diving since it allows for more deep time than air. The kind of Nitrox is determined by the amount of oxygen in the mixture (e.g. EAN32 means a breathing gas mixture containing 32 percent Oxygen and 68 percent Nitrogen). The partial pressure of Oxygen and the maximum operational depth should be carefully controlled while using Nitrox, since excessive Oxygen partial pressure might have negative effects on human physiology.

3.1 Oxygen Toxicity

Long-term inhalation of oxygen at a high partial pressure may be harmful to the body; oxygen becomes poisonous when there are too many molecules in our cells. There are two types of oxygen toxicity that can damage divers: pulmonary toxicity and central nervous system (CNS) toxicity. Divers who conduct very lengthy technical dives (in the range of six to twelve hours or more) and divers who conduct recurrent technical dives over a period of days or weeks might develop pulmonary oxygen poisoning. Divers, both recreational nitrox divers and technical divers, are concerned about oxygen toxicity of the central nervous system. CNS toxicity can occur after only a few minutes of exposure to high partial pressures of oxygen, and the illness can attack without warning. The sickness begins at the molecular level, affecting the complex of tissues in the brain and spinal cord, resulting in tissue damage and seizures (U.S. Navy Diving Manual 2011).

The oxygen limit's pressure component is determined using partial pressures, which are computed by multiplying the percentage of oxygen in the tank by the atmospheres of pressure at the planned depth. Air contains 21% oxygen and 79% nitrogen at atmospheric pressure (1ATA). Thus, the partial pressure of oxygen is 0.210 ATA and the partial pressure of nitrogen is 0.790 ATA. For example, a diver breathing air (21% O2) at 40 m (5 atm) is breathing a partial pressure of oxygen (PPO2) of 1.05. (5 atm x 0.21 = 1.05)

The critical oxygen partial pressure value for oxygen toxicity (poisoning) is between 1.4 and 1.6 ATA. The same example with a gas mixture of %40 of oxygen (EAN 40) would be dangerous. At 40 m (5 atm), partial pressure of oxygen is 2 (5 atm x 0.4 = 2) which is greater than 1.6.

3.2 Nitrogen Narcosis

Nitrogen narcosis might potentially be an issue for the diver. Gases in the body create nitrogen narcosis, which is defined by Dalton's Law of partial pressures, which states that the total pressure of a gas mixture equals the sum of the partial pressures of the gases in the mixture. As the overall gas pressure rises with increasing dive depth, the partial pressure of nitrogen rises, and more nitrogen is dissolved in the blood.

The initial signs and symptoms appear about 30 m (4 Atm) and get more severe as the depth increases. Laughter, loquacity, and a lightheaded sensation, as well as sensations of exhilaration and enthusiasm, may be noticeable. It may be possible to overcome such habit to some extent by increasing self-control efforts. As is common with hypoxia, mental activity slows down, with delays in auditory and olfactory cues and a predisposition to word-idea fixation. Because of the existence of overconfidence, the consequent restriction in the abilities of association and perception is extremely harmful.

Nitrogen narcosis can be avoided in a variety of methods. The first option would be to limit the depth of a dive; however this would be ineffective for professional dives. It is generally recognized that a diver's maximum depth limit when using compressed air is 30 to 50 meters. In addition, to avoid nitrogen narcosis, a gas combination other than air is recommended. For dives deeper than 50 meters, diluent gases like as helium or helium-nitrogen are often used instead of oxygen. Helium has not been shown to have an anesthetic or narcotic effect on divers at depth breathing compressed gases (Kirkland, et al., 2020).

3.3 Decompression Sickness

Decompression sickness is also another disease caused by nitrogen. More Nitrogen is dissolved in various human tissues when the diver spends more time underwater at increased ambient pressure. The amount of Nitrogen absorbed by a tissue is determined by the tissue loading capacity and speed. Tissue loading capacity is the maximum quantity of nitrogen that a tissue can absorb; whereas tissue loading speed is the time it takes for a tissue to acquire a given level of absorbed gas. As the partial pressure of nitrogen in the breathing gas improves, these values increase as well. If a diver ascends too rapidly after a lengthy dive, the excessive Nitrogen in the tissues might produce bubbles, resulting in Decompression Sickness (DCS). To minimize the danger of DCS, the diver should ascend slowly and enable the body's extra Nitrogen to be removed. To estimate tissue loads and identify safe ascending protocols, several models have been developed (A. Bühlmann 1984).

3.4 Bühlmann Algorithm

We utilize Bühlmann's model to compute the dive profile for a particular breathing gas combination in this study. The depths and time spent on various depths are referred to as the dive profile. As the percentage of Nitrogen in the air changes, so does the diving profile. As a consequence, the length of the dive and the amount of breathing gas consumed vary. The breathing gas supply is considered to be infinite in this research. Haldane's researches provide the foundation for Bühlmann's Model. Bühlmann proposes 16 tissues instead of 5 and offers associated coefficients. The single gas model of Bühlmann is illustrated in the figure below.

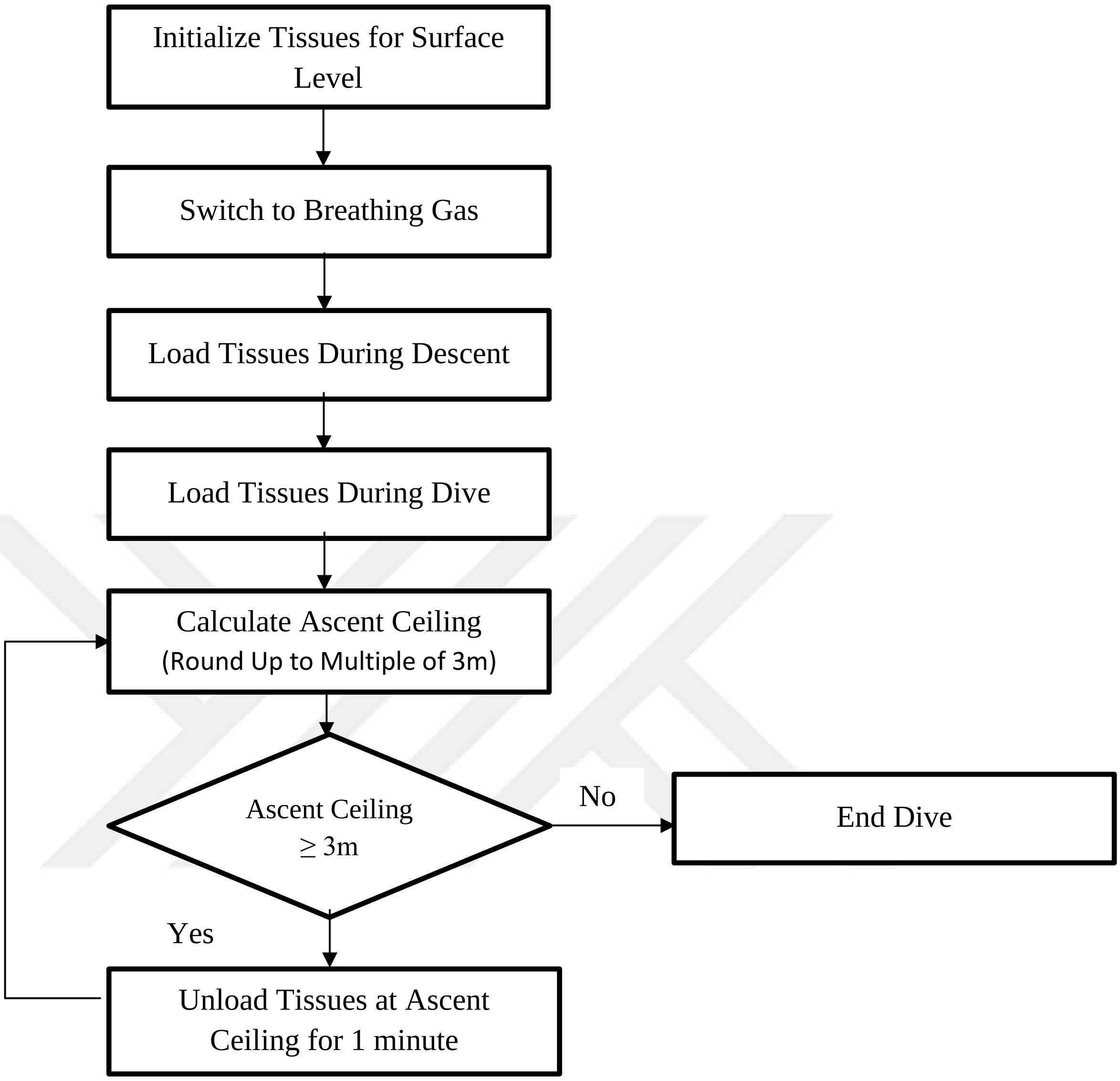


Figure 3.1: Bühlmann’s Single Gas Model

Step 1: Initialize the tissues

The pressure at sea level is approximately 1 bar. Bühlmann’s model considers the human body to 16 tissues. For each tissue, the initial partial pressure of Nitrogen is calculated.

Step 2: The Descent

During the descent, a significant amount of Nitrogen might be dissolved in the tissues before the professional divers' duty begins. The quantity of dissolved Nitrogen in each tissue is determined.

Step 3: The Dive

During the dive we assume that the diver works at a constant depth. In this step, nitrogen continues to dissolve in the tissues. The amount of dissolved nitrogen in each tissue is calculated.

Step 4: Calculate the Ascent Ceiling

A safe ascension ceiling is computed for each tissue.

Step 5: First Decompression Stop

The tissues' deepest ascent ceiling is determined and rounded up to the nearest multiple of 3m (3m, 6m …).

Step 6: Unloading the tissues

The diver unload the tissues for 1 minute during the first decompression stop then check if the tissues are unloaded enough for the current depth or not. If not, the diver unloads the tissues for 1 minute again. If yes, the diver ascends to a shallower stop.

Step 7: End the dive

The dive ends if all the tissues are unloaded.

A professional diver can utilize a variety of gases (EANx, Heliox, Trimix, etc.) to reduce dive time. Enriched air nitrox (EANx), sometimes known as just Nitrox, is the second most often used diving gas after air. When we dive, our bottom time is limited by two factors: gas usage and nitrogen absorption. Nitrox is just a mixture of oxygen and nitrogen with a greater oxygen content than air. We can stay at depth for longer by limiting the quantity of nitrogen we breathe when diving, but we can't go as deep as we might with air because of the greater amount of oxygen. The multiple gas model of Bühlmann is represented in the figure below:

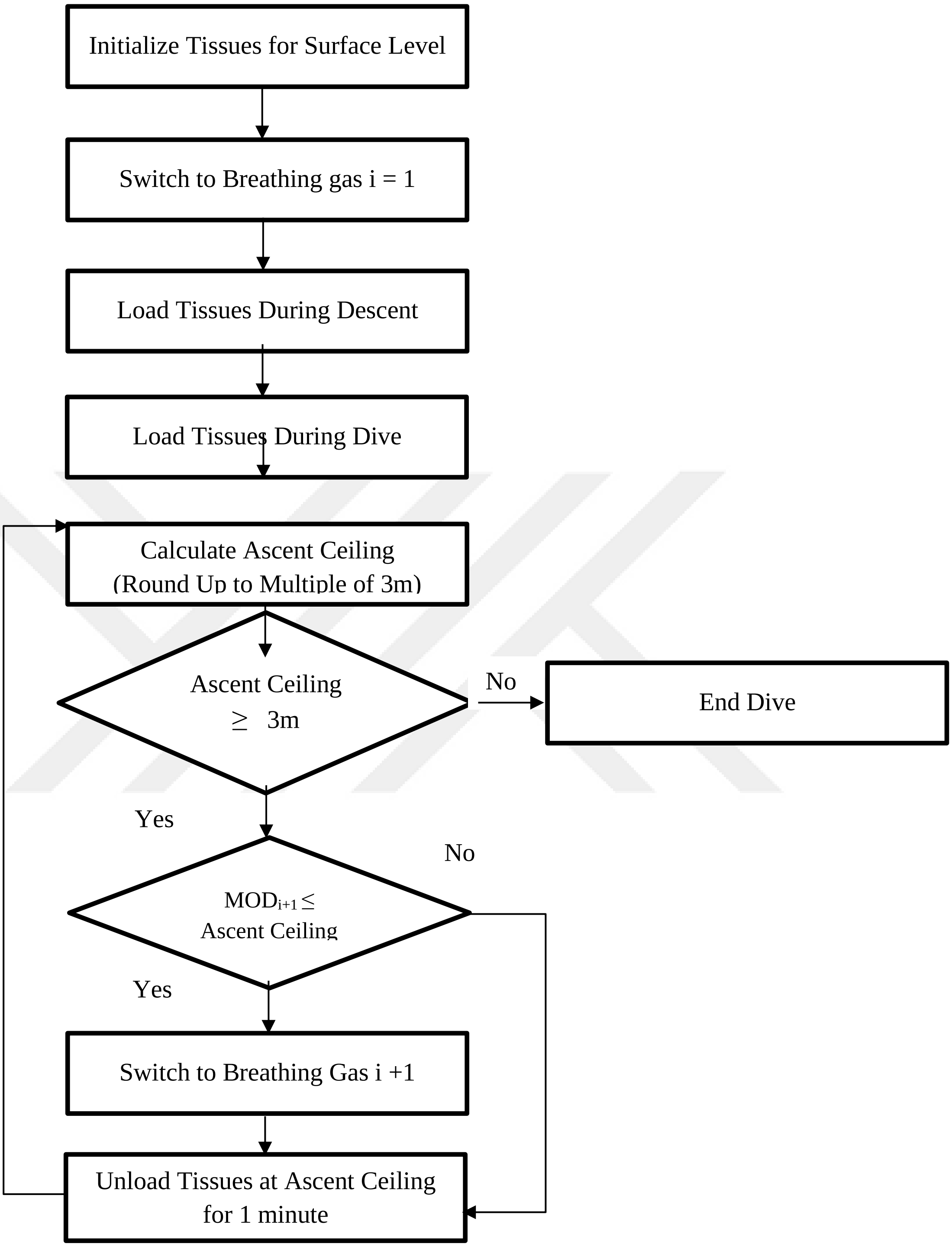


Figure 3.2: Bühlmann's Multiple Gas Model

This model aims to switch to the suitable gas by considering maximum operational depth (MOD) if there is a more suitable gas that can be used for every each decompression stop. For the works that cannot be completed in a single dive, Bühlmann's multiple gas with multiple dives model is shown in the figure below.

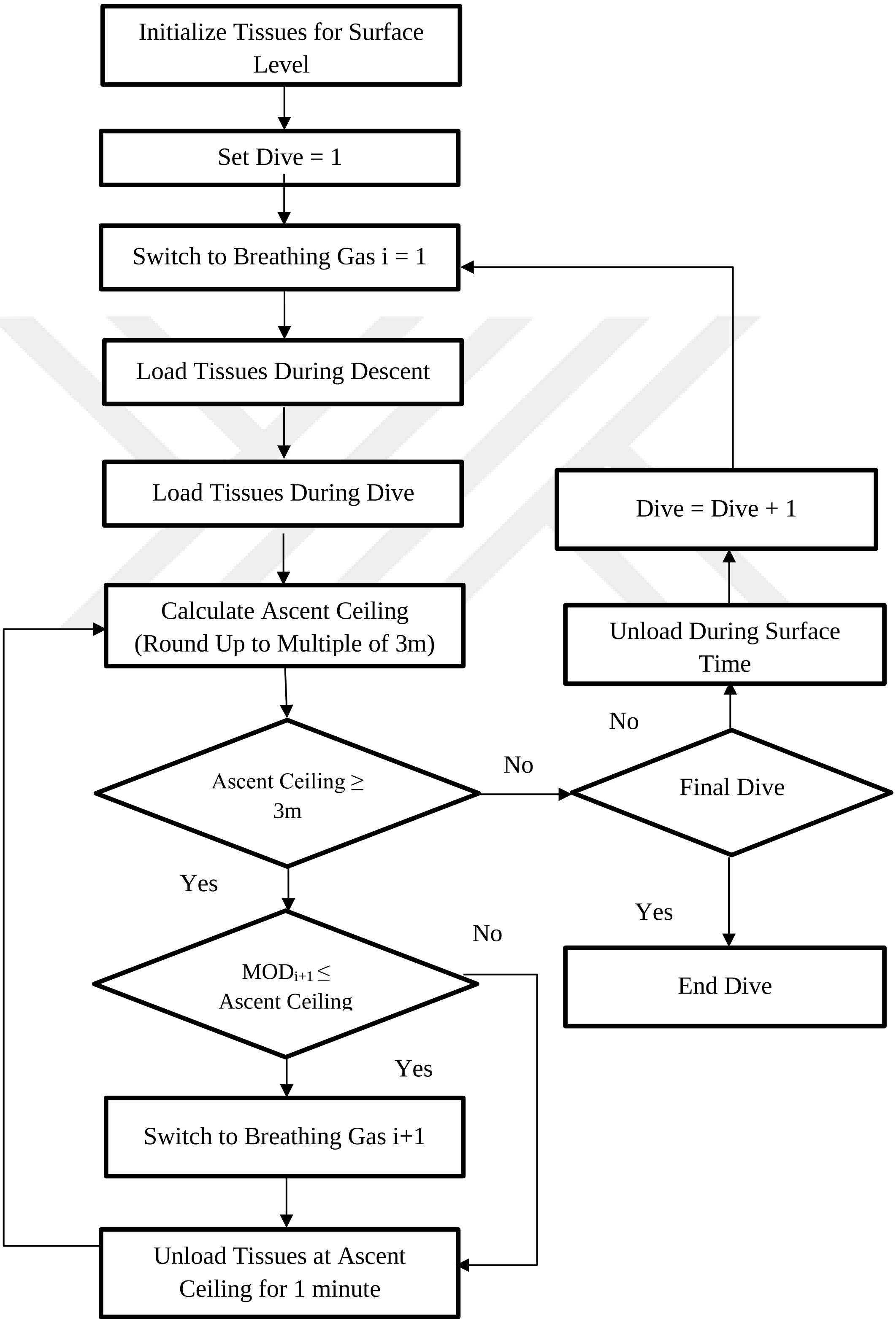


Figure 3.3: Bühlmann's Multiple Gas with Repetitive Dive Model

In a multiple dive scenario, the diver repeats the same steps as in multiple gas scenarios. The difference is that the diver should unload the tissues during surface time between the repetitive dives.

3.5 Cost Related to Professional Diving

There are various sorts of costs in professional diving. The cost of the diver and the cost of breathing gas are the two primary expenses examined in this study. The cost of a diver is considered to be hourly. Because the breathing gas is considered to be made by enriching air with oxygen, the sole expense is the addition of pure oxygen to the breathing gas to make the Nitrox combination. Both the diver and breathing gas costs will increase as the dive time increases. The dive period is separated into two parts, the first of which is the dive itself, during which the professional diver performs several duties. The diver should begin the ascent procedure whenever all or part of the duties has been performed. The diver is deemed idle during the second stage since he or she is not performing any tasks. The goal is to cut down on the diver's idle time. To do this, the percent of nitrogen in the breathing gas should be reduced while the percentage of oxygen in the breathing gas should be augmented, resulting in an increase in the cost of breathing gas. The goal of this research is to establish a balance between these two expenses in order to reduce the overall cost. The cost of a diver is easy to calculate.

$$C_1 = t\, c_1 \qquad (1)$$

The total dive duration in hours is t, and the hourly diver fee is c_1. The cost of breathing gas is determined by the number of liters of gas utilized during the dive and the cost of breathing gas per liter. The amount of gas used is related to the depth because as the ambient pressure increases, so does the pressure of breathing gas. Let *p(t)* be the ambient pressure at time t, and r indicate the diving rate in liters per hour. The total surface equivalent gas consumed during the dive may therefore be computed as follows:

$$\int p(t)\, r\, dt \tag{2}$$

The only expense for inhaling gas is oxygen, because nitrox is made by combining air and oxygen. Assume FO_2 is the required oxygen fraction in the final breathing gas. The quantity of pure oxygen delivered to 1 liter of breathing gas is (FO_2-0.21)/0.79. The cost of breathing gas per liter is calculated by multiplying this amount by the cost of oxygen.

$$c_2\, (FO_2 - 0.21)/0.79 \tag{3}$$

Where, c_2 is the cost of Oxygen per liter at an ambient pressure of 1 bar. Lastly, multiply the amount of gas consumed by the cost of breathing gas to get the overall cost of breathing gas.

$$C_2 = \int p(t)\, r\, dt\;\; c_2\, (FO_2 - 0.21)/0.79 \tag{4}$$

If multiple breathing gases are supplied to the diver for different depths, the corresponding cost should be calculated and summed for related depths. The total dive cost is the sum of diver cost and breathing gas cost.

$$C = c_1 + c_2 \tag{5}$$

The objective is to minimize the total dive cost. Different gas mixtures will have different costs for the same dive profiles. In this study, we anticipate using the genetic algorithm to find the most cost-effective gas mixture.

3.6 Genetic Algorithm

Genetic Algorithms (GA) are randomized search algorithms designed to mimic the mechanics of natural selection and genetics. Genetic algorithms function with string structures, which are analogous to biological structures that develop over time using a randomized but well-organized information exchange to obey the survival of the fittest criterion. As a consequence, each generation produces a new collection of strings based on the fittest individuals of the previous generation. First, the code that will be used must be specified. After that, a random method is used to generate an initial population of strings. Next, using a set of operators, this initial population is utilized to generate subsequent populations, which should improve with time. Following the formation of the initial population, the fitness function values are evaluated. The fitness function determines an individual's level of fitness (the ability of an individual to compete with other individuals). It assigns each person a fitness score. The fitness score determines the probability of an individual being chosen for reproduction. After the evaluation of fitness function values, if the successive population’s performance is satisfactory, then the algorithm stops. If not, the main operators of the Genetic Algorithms show up. The main operators are reproduction, crossover, and mutation (Holland 1992).

Reproduction (also known as selection) is a method of increasing the number of copies of superior strings in a new population. The first operation on a population is generally reproduction. In a population, reproduction chooses good strings and creates a mating pool. When two strings are recombined to make a better string, the crossover operator is utilized. Recombination develops distinct people in succeeding generations in crossover operation by mixing material from two people from the preceding generation. Mutation contributes new information to the genetic search process and helps to avoid getting trapped at local optima. It's an operator that adds variation to a population when it's becoming homogeneous owing to the usage of reproduction and crossover operators repeatedly. This generational process continues until a termination condition is met. The following are examples of common termination conditions:

- The fitness of the highest-ranking solution is approaching or has reached a point where subsequent iterations no longer provide better outcomes,

- A solution is found that satisfies the basic requirements,
- There are a certain number of generations that must be reached.

In this study, the fitness function is the total cost. The cost varies according to the different oxygen values in the gas mixtures. Thus, oxygen values in the gas mixtures are continuous decision variables which vary between 0 and 1. Here GA tries to find a more cost-effective mix with each new generation. The algorithm ends when the improvement from one generation to the next is insignificant.

4. NUMERICAL APPLICATION

Two hypothetical problems are solved to illustrate the proposed model. The first problem is considered as a single dive and the second problem is considered as a repetitive dive. The cost of a diver for an hour is supposed to be $30, while the cost of oxygen per liter is supposed to be 2 cents. According to DAN, the highest limit for fraction of oxygen is set to 30% (Donald 1947, Lang 2001). As the decompression times are shorter, we allowed a partial pressure of 1.6 bar of Oxygen for decompression stops. Each numerical example is solved with MATLAB using the Genetic Algorithm of Global Optimization Toolbox and the outputs are presented in Appendix A.

4.1 Single Dive Scenario

The first problem is considered as a single dive and the diver performs the task at a depth of 40 m for 120 min. We first consider a single gas mixture and obtained the following dive profile and dive cost:

Table 4.1: Single Gas Mixture and Single Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	29.85
40	40	120	29.85
15	15	3	29.85
12	12	16	29.85
9	9	27	29.85
6	6	47	29.85
3	3	100	29.85

Table 4.2: Dive Cost for Single Gas Mixture and Single Dive

Diver Cost	Gas Cost	Total Cost
158.5	51.0378	209.5378

Then, we allowed an additional gas for decompression and obtained the following results:

Table 4.3: Two Gas Mixtures and Single Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	29.59
40	40	120	29.59
15	15	3	29.59
12	12	10	72.73
9	9	15	72.73
6	6	25	72.73
3	3	46	72.73

Table 4.4: Dive Cost for Two Gas Mixtures and Single Dive

Diver Cost	Gas Cost	Total Cost
111.5	82.8854	194.3854

As expected, the total dive cost has decreased. Next, we allowed another additional gas for decompression and obtained the following results:

Table 4.5: Three Gas Mixtures and Single Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	27.88
40	40	120	27.88
15	15	4	64
12	12	11	64
9	9	17	64
6	6	21	99.62
3	3	37	99.62

Table 4.6: Dive Cost for Three Gas Mixtures and Single Dive

Diver Cost	Gas Cost	Total Cost
107	85.4070	192.4070

Again, the total gas cost has decreased. Next, we allowed another additional gas for decompression and obtained the following results:

Table 4.7: Four Gas Mixtures and Single Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	27.36
40	40	120	27.36
15	15	5	29.59
12	12	10	72.49
9	9	16	72.49
6	6	21	99.91
3	3	37	99.91

Table 4.8: Dive Cost for Four Gas Mixtures and Single Dive

Diver Cost	Gas Cost	Total Cost
106.5	85.4201	191.9201

The gas cost only decreased marginally, we continued to allow additional gas for decompression and obtained the following results:

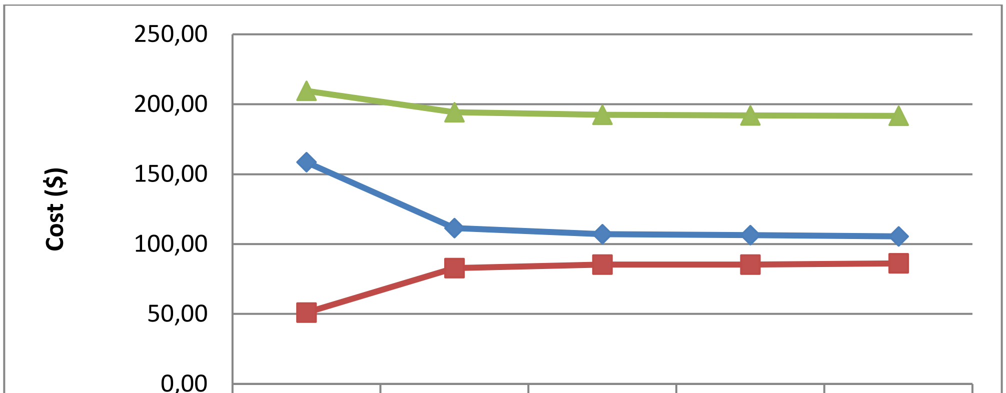
Table 4.9: Five Gas Mixtures and Single Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	27.57
40	40	120	27.57
15	15	4	62.53
12	12	11	69.13
9	9	14	84.21
6	6	21	98.52
3	3	37	98.52

Table 4.10: Dive Cost for Five Gas Mixtures and Single Dive

Diver Cost	Gas Cost	Total Cost
105.5	86.1788	191.6788

The decrease in total cost is very marginal, so we did not add additional gas. Comparison of the costs of different gas mixtures is given in the chart below:



	Single Gas Mixture	2 Gas Mixtures	3 Gas Mixtures	4 Gas Mixtures	5 Gas Mixtures
Diver Cost	158,50	111,50	107,00	106,50	105,50
Gas Cost	51,04	82,89	85,41	85,42	86,18
Total Cost	209,54	194,39	192,41	191,92	191,68

Figure 4.1: Costs for Different Number of Gas Mixtures in Single Dive Scenario

To sum up we observe the diver cost decreases as the number of additional decompression gas increases. The results show that the diver needs less time for decompression hence the idle time decreases. On the other hand, the gas cost increases gradually as the number of decompression gas increase. This is due to the fact that additional gases are richer with oxygen which increases the mixture cost. In total the cost decreases, but the most significant decrease happens with the addition of the second gas. The addition of the third gas further decreases total cost but just marginally. With the addition of fourth and fifth gases the decrease in cost is negligible. Also, by examining the fractions of gases with 5 mixtures, we observe that the first gas is air with %30 of oxygen and the last decompression mixture is almost pure oxygen with a fraction of more than %99 of oxygen. This last oxygen is only utilized at depths shallower than 6 meters as at this depth the partial pressure of pure oxygen is 1.6 which is the maximum limit considered being safe.

4.2 Repetitive Dive Scenario

The second problem is considered as a repetitive dive. So, primarily the diver performs the task at a depth of 40 m for 120 min. After unloading tissues during surface time for 120 min, the diver performs again the task at a depth of 40m for 120 min. We consider a single gas mixture with repetitive dive scenario and obtained the following dive profile and dive cost:

Table 4.12: Single Gas Mixture and Repetitive Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	29.99
40	40	120	29.99
15	15	3	29.99
12	12	16	29.99
9	9	26	29.99
6	6	47	29.99
3	3	100	29.99
0	0	120	21
0	40	4	29.99
40	40	120	29.99
15	15	3	29.99
12	12	17	29.99
9	9	33	29.99
6	6	89	29.99
3	3	244	29.99

Table 4.13: Dive Cost for Single Gas Mixture and Repetitive Dive

Diver Cost	Gas Cost	Total Cost
473	118.7741	591.7741

Then, we allowed an additional gas for decompression and obtained the following results:

Table 4.14: Two Gas Mixtures and Repetitive Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	29.91
40	40	120	29.91
15	15	3	29.91
12	12	10	72.72
9	9	14	72.72
6	6	25	72.72
3	3	46	72.72
0	0	120	21
0	40	4	29.91
40	40	120	29.91
15	15	3	29.91
12	12	10	72.72
9	9	18	72.72
6	6	42	72.72
3	3	97	72.72

Table 4.15: Dive Cost for Two Gas Mixtures and Repetitive Dive

Diver Cost	Gas Cost	Total Cost
318	200.1108	518.1108

As expected, the total dive cost has decreased. Next, we allowed another additional gas for decompression and obtained the following results:

Table 4.16: Three Gas Mixtures and Repetitive Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	29.99
40	40	120	29.99
15	15	3	29.99
12	12	10	72.65
9	9	14	72.65
6	6	20	98.91
3	3	36	98.91
0	0	120	21
0	40	4	29.99
40	40	120	29.99
15	15	3	29.99
12	12	10	72.65
9	9	18	72.65
6	6	32	98.91
3	3	73	98.91

Table 4.17: Dive Cost for Three Gas Mixtures and Repetitive Dive

Diver Cost	Gas Cost	Total Cost
293.5000	215.6190	509.1190

Again, the total gas cost has decreased. Next, we allowed another additional gas for decompression and obtained the following results:

Table 4.18: Four Gas Mixtures and Repetitive Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	29.86
40	40	120	29.86
15	15	2	57.60
12	12	10	71.89
9	9	15	71.89
6	6	19	99.73
3	3	36	99.73
0	0	120	21
0	40	4	29.86
40	40	120	29.86
15	15	2	57.60
12	12	10	71.89
9	9	18	71.89
6	6	32	99.73
3	3	72	99.73

Table 4.19: Dive Cost for Four Gas Mixtures and Repetitive Dive

Diver Cost	Gas Cost	Total Cost
292	215.9744	507.9744

The gas cost only decreased marginally, we continued to allow additional gas for decompression and obtained the following results:

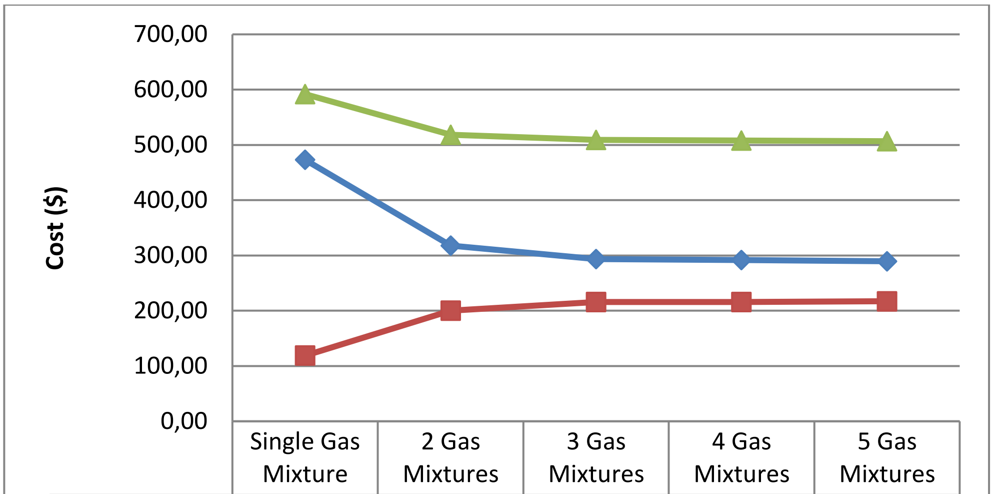
Table 4.20: Five Gas Mixtures and Repetitive Dive

From (m)	To (m)	Duration (min)	Oxygen %
0	40	4	29.87
40	40	120	29.87
15	15	2	55.83
12	12	10	71.69
9	9	13	84.21
6	6	19	99.80
3	3	36	99.80
0	0	120	21
0	40	4	29.87
40	40	120	29.87
15	15	2	55.83
12	12	10	71.69
9	9	16	84.21
6	6	32	99.80
3	3	71	99.80

Table 4.21: Dive Cost for Five Gas Mixtures and Repetitive Dive

Diver Cost	Gas Cost	Total Cost
289.5000	217.1752	506.6752

The decrease in total cost is very marginal, so we did not add additional gas. Comparison of the costs of different gas mixtures is given in the chart below:



	Single Gas Mixture	2 Gas Mixtures	3 Gas Mixtures	4 Gas Mixtures	5 Gas Mixtures
Diver Cost	473,00	318,00	293,50	292,00	289,50
Gas Cost	118,77	200,11	215,62	215,97	217,18
Total Cost	591,77	518,11	509,12	507,97	506,68

Figure 4.2: Costs for Different Number of Gas Mixtures in Repetitive Dive Scenario

To sum up we observe the diver cost decreases as the number of additional decompression gas increases. The results show that the diver needs less time for decompression hence the idle time decreases. On the other hand, the gas cost increases gradually as the number of decompression gas increase. This is due to the fact that additional gases are richer with oxygen which increases the mixture cost. In total the cost decreases, but the most significant decrease happens with the addition of the second gas. The addition of the third gas further decreases total cost but just marginally. With the addition of fourth and fifth gases the decrease in cost is negligible. Also, by examining the fractions of gases with 5 mixtures, we observe that the first gas is air with %30 of oxygen and the last decompression mixture is almost pure oxygen with a fraction of more than %99 of oxygen. This last oxygen is only utilized at depths shallower than 6 meters as at this depth the partial pressure of pure oxygen is 1.6 which is the maximum limit considered being safe.

5. CONCLUSION

Men have gone into the ocean to gather food since the beginning of human life, but it is hard to distinguish the precise date or origin of diving. We know from fossils that as long as 4,500 years ago, Mesopotamian people participated in diving as a means of trade, typically gathering pearl oysters. Professional diving activities have expanded dramatically as a result of technology improvements in the last century. Professional diving is when divers get payments for their efforts. Professional diving is divided into various disciplines, the most well-known of which being commercial diving. Commercial diving is an application of professional diving in which the diver does underwater work for industrial, construction, engineering, maintenance, or other commercial objectives that are comparable to work performed outside of the water, with the diving being secondary to the activity. During these works, divers must abide by the diving rules. The slightest carelessness can result in serious accidents. Researchers have investigated the physiological implications of high ambient pressure extensively, and several models have been presented. Industrial optimization studies, on the other hand, are quite restricted. The goal of this study was to analyze the expenses of professional dives and suggest a methodology to reduce these expenditures while reducing DCS risks. There are various sorts of costs in professional diving. The cost of the diver and the cost of breathing gas are the two primary expenses examined in this study. Because the breathing gas is considered to be made by enriching air with oxygen, the sole expense is the addition of pure oxygen to the breathing gas to make the Nitrox combination. Enriching the breathing gas with oxygen decreases the dive time. As a result, the diver works less. Thus, the diver cost is reduced. But enriching the breathing gas with oxygen also increases the gas cost. The objective is to find the balance between gas cost and diver cost for different scenarios by adhering to diving rules.

In previous studies, we had considered a single gas supply for both the dive and the decompression stops. This approach restricts the fraction of the Oxygen in the breathing gas mixture significantly. Allowing additional gas mixtures for decompression greatly increases the flexibility of the model as Oxygen rich mixtures which cannot be used during deeper dives can be used during the decompression stops. Even though this approach increases the gas mixture cost, this additional cost is mitigated by the reduction of decompression stop times and as a result the total dive time. As suspected, by allowing additional decompression gas mixtures, the total dive cost decreases gradually. Two hypothetical situations are used to demonstrate the suggested paradigm, which has been shown to be beneficial in real-world circumstances. Bühlmann's decompression model is used in our model because it is freely available. Other decompression models are easily adaptable to a variety of professional diving applications.

We assumed a limitless supply of breathing gas including solely oxygen and nitrogen in our study. Other gases, such as helium, may be included in future research. Unlimited gas supply is only possible if the gas is obtained from the surface, which is not always possible. In that circumstance, a restricted supply of breathing gas should be considered.

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APPENDICES

Appendix A.

```
>> optimize_dive(1)

                                  Best          Max          Stall
Generation   Func-count           f(x)      Constraint   Generations
    1           25250          209.616            0          0
    2           50000          209.616            0          1
    3           74750          209.616            0          2
    4           99500          209.538            0          0
    5          124250          209.538            0          1
    6          149000          209.538            0          2
    7          173750          209.538            0          3
    8          198500          209.538            0          4
    9          223250          209.538            0          5
   10          248000          209.538            0          6
   11          272750          209.538            0          7

Optimization terminated: average change in the fitness value
less than options. Function Tolerance and constraint violation
is less than options.

d_profile =

         0   40.0000    4.0000    0.7015         0
   40.0000   40.0000  120.0000    0.7015         0
   15.0000   15.0000    3.0000    0.7015         0
   12.0000   12.0000   16.0000    0.7015         0
    9.0000    9.0000   27.0000    0.7015         0
    6.0000    6.0000   47.0000    0.7015         0
    3.0000    3.0000  100.0000    0.7015         0
         0         0         0    0.7900         0

  diver_cost = 158.5000

  gas_cost   = 51.0378

  total_cost = 209.5378
```

```
>> optimize_dive(2)

                                  Best       Max        Stall
Generation  Func-count            f(x)     Constraint  Generations
    1          25250         194.428            0       0
    2          50000         194.389            0       0
    3          74750         194.389            0       1
    4          99500         194.389            0       2
    5         124250         194.389            0       3
    6         149000         194.387            0       0
    7         173750         194.387            0       0
    8         220825         194.386            0       0
    9         282625         194.385            0       0
   10         307375         194.385            0       1
   11         332125         194.385            0       2

Optimization terminated: average change in the fitness value
less than options. Function Tolerance and constraint violation
is less than options.

   d_profile =

         0   40.0000    4.0000    0.7041         0
   40.0000   40.0000  120.0000    0.7041         0
   15.0000   15.0000    3.0000    0.7041         0
   12.0000   12.0000   10.0000    0.2727         0
    9.0000    9.0000   15.0000    0.2727         0
    6.0000    6.0000   25.0000    0.2727         0
    3.0000    3.0000   46.0000    0.2727         0
         0         0         0    0.7900         0


diver_cost =  111.5000


gas_cost   =  82.8854


total_cost =  194.3854
```

```
>> optimize_dive(3)

                                  Best       Max        Stall
Generation  Func-count           f(x)     Constraint  Generations
    1          25250         192.418           0        0
    2          50000         192.412           0        0
    3          74750         192.412           0        0
    4          99500          192.41           0        0
    5         124250         192.407           0        0
    6         149000         192.407           0        0
    7         173750         192.407           0        1
    8         198500         192.407           0        0
    9         223250         192.407           0        1
   10         248000         192.407           0        2
   11         272750         192.407           0        3

Optimization terminated: average change in the fitness value
less than options. Function Tolerance and constraint violation
is less than options.

d_profile =

         0   40.0000    4.0000    0.7212         0
   40.0000   40.0000  120.0000    0.7212         0
   15.0000   15.0000    4.0000    0.3600         0
   12.0000   12.0000   11.0000    0.3600         0
    9.0000    9.0000   17.0000    0.3600         0
    6.0000    6.0000   21.0000    0.0038         0
    3.0000    3.0000   37.0000    0.0038         0
         0         0         0    0.7900         0


diver_cost =   107


gas_cost   =   85.4070


total_cost =   192.4070
```

```
 >> optimize_dive(4)

                                    Best       Max        Stall
Generation  Func-count              f(x)     Constraint  Generations
    1          25250       191.967             0       0
    2          50000       191.949             0       0
    3          74750       191.949             0       1
    4          99500       191.949             0       0
    5         124250       191.949             0       0
    6         159450        191.93             0       0
    7         184200        191.93             0       0
    8         310600       191.922             0       0
    9         477850        191.92             0       0
   10         513050        191.92             0       0
   11         580550        191.92             0       0

Optimization terminated: average change in the fitness value
less than options. Function Tolerance and constraint violation
is less than options.

d_profile =

         0   40.0000    4.0000    0.7264         0
   40.0000   40.0000  120.0000    0.7264         0
   15.0000   15.0000    5.0000    0.4249         0
   12.0000   12.0000   10.0000    0.2751         0
    9.0000    9.0000   16.0000    0.2751         0
    6.0000    6.0000   21.0000    0.0009         0
    3.0000    3.0000   37.0000    0.0009         0
         0         0         0    0.7900         0


diver_cost =  106.5000


gas_cost   =  85.4201


total_cost =  191.9201
```

```
>> optimize_dive(5)

                                 Best         Max          Stall
Generation   Func-count          f(x)      Constraint   Generations
    1          25250          191.693            0       0
    2          50000          191.682            0       0
    3          74750          191.682            0       0
    4          99500          191.682            0       0
    5         124250          191.682            0       0
    6         149000          191.682            0       0
    7         173750          191.681            0       0
    8         268325          191.679            0       0
    9         316825          191.679            0       0
   10         341575          191.679            0       1
   11         382475          191.679            0       0

Optimization  terminated:  average  change  in  the  fitness  value
less  than options.  Function  Tolerance and  constraint  violation
is less than options.
  d_profile =

         0   40.0000    4.0000    0.7243         0
   40.0000   40.0000  120.0000    0.7243         0
   15.0000   15.0000    4.0000    0.3747         0
   12.0000   12.0000   11.0000    0.3087         0
    9.0000    9.0000   14.0000    0.1579         0
    6.0000    6.0000   21.0000    0.0148         0
    3.0000    3.0000   37.0000    0.0148         0
         0         0         0    0.7900         0


diver_cost =   105.5000


gas_cost   =   86.1788


total_cost =   191.6788
```

```
>> optimize_dive(1)

                                  Best        Max         Stall
Generation   Func-count           f(x)     Constraint   Generations
    1          25250        591.774             0        0
    2          50000        591.774             0        1
    3          74750        591.774             0        2
    4          99500        591.774             0        3
    5         124250        591.774             0        4
    6         149000        591.774             0        5
    7         173750        591.774             0        6
    8         198500        591.774             0        7
    9         223250        591.774             0        8
   10         248000        591.774             0        9
   11         272750        591.774             0       10

Optimization terminated: average change in the fitness value
less than options. Function Tolerance and constraint violation
is less than options.

d_profile =

         0   40.0000    4.0000    0.7001         0
   40.0000   40.0000  120.0000    0.7001         0
   15.0000   15.0000    3.0000    0.7001         0
   12.0000   12.0000   16.0000    0.7001         0
    9.0000    9.0000   26.0000    0.7001         0
    6.0000    6.0000   47.0000    0.7001         0
    3.0000    3.0000  100.0000    0.7001         0
         0         0  120.0000    0.7900         0
         0   40.0000    4.0000    0.7001         0
   40.0000   40.0000  120.0000    0.7001         0
   15.0000   15.0000    3.0000    0.7001         0
   12.0000   12.0000   17.0000    0.7001         0
    9.0000    9.0000   33.0000    0.7001         0
    6.0000    6.0000   89.0000    0.7001         0
    3.0000    3.0000  244.0000    0.7001         0
         0         0         0    0.7900         0


diver_cost  =   473


gas_cost    =   118.7741

total_cost  =   591.7741
```

```
>> optimize_dive(2)

                                  Best         Max         Stall
Generation   Func-count           f(x)     Constraint   Generations
    1           25250          518.139            0        0
    2           50000          518.139            0        1
    3           74750          518.138            0        0
    4           99500          518.138            0        1
    5          124250          518.117            0        0
    6          149000          518.111            0        0
    7          173750          518.111            0        1
    8          198500          518.111            0        2
    9          223250          518.111            0        3
   10          248000          518.111            0        4
   11          272750          518.111            0        5

Optimization terminated: average change in the fitness value
less than options. Function Tolerance and constraint violation
is less than options.

d_profile =

         0   40.0000    4.0000    0.7009         0
   40.0000   40.0000  120.0000    0.7009         0
   15.0000   15.0000    3.0000    0.7009         0
   12.0000   12.0000   10.0000    0.2728         0
    9.0000    9.0000   14.0000    0.2728         0
    6.0000    6.0000   25.0000    0.2728         0
    3.0000    3.0000   46.0000    0.2728         0
         0         0  120.0000    0.7900         0
         0   40.0000    4.0000    0.7009         0
   40.0000   40.0000  120.0000    0.7009         0
   15.0000   15.0000    3.0000    0.7009         0
   12.0000   12.0000   10.0000    0.2728         0
    9.0000    9.0000   18.0000    0.2728         0
    6.0000    6.0000   42.0000    0.2728         0
    3.0000    3.0000   97.0000    0.2728         0
         0         0         0    0.7900         0


diver_cost =   318


gas_cost   =   200.1108


total_cost =   518.1108
```

```
>> optimize_dive(3)

                                  Best        Max         Stall
Generation   Func-count           f(x)     Constraint  Generations
    1          25250           509.122            0       0
    2          50000           509.122            0       0
    3          74750           509.122            0       1
    4          99500           509.122            0       2
    5         124250           509.122            0       3
    6         149000            509.12            0       0
    7         173750            509.12            0       0
    8         198500            509.12            0       1
    9         223250            509.12            0       2
   10         262725            509.12            0       0
   11         293175           509.119            0       0

Optimization terminated: average change in the fitness value
less than options. Function Tolerance and constraint violation
is less than options.

  d_profile =

         0   40.0000    4.0000    0.7001         0
   40.0000   40.0000  120.0000    0.7001         0
   15.0000   15.0000    3.0000    0.7001         0
   12.0000   12.0000   10.0000    0.2735         0
    9.0000    9.0000   14.0000    0.2735         0
    6.0000    6.0000   20.0000    0.0109         0
    3.0000    3.0000   36.0000    0.0109         0
         0         0  120.0000    0.7900         0
         0   40.0000    4.0000    0.7001         0
   40.0000   40.0000  120.0000    0.7001         0
   15.0000   15.0000    3.0000    0.7001         0
   12.0000   12.0000   10.0000    0.2735         0
    9.0000    9.0000   18.0000    0.2735         0
    6.0000    6.0000   32.0000    0.0109         0
    3.0000    3.0000   73.0000    0.0109         0
         0         0         0    0.7900         0


diver_cost =   293.5000


gas_cost   =   215.6190


total_cost =   509.1190
```

```
>> optimize_dive(4)

                                  Best       Max        Stall
Generation  Func-count            f(x)     Constraint  Generations
    1          25250         507.977            0       0
    2          50000         507.977            0       0
    3          74750         507.977            0       1
    4          99500         507.977            0       0
    5         124250         507.977            0       0
    6         149000         507.977            0       0
    7         173750         507.976            0       0
    8         198500         507.976            0       1
    9         223250         507.976            0       2
   10         328275         507.974            0       0
   11         353025         507.974            0       1
Optimization terminated: average change in the fitness value
less than options. Function Tolerance and constraint violation
is less than options.

d_profile =

         0   40.0000    4.0000    0.7014         0
   40.0000   40.0000  120.0000    0.7014         0
   15.0000   15.0000    2.0000    0.4240         0
   12.0000   12.0000   10.0000    0.2811         0
    9.0000    9.0000   15.0000    0.2811         0
    6.0000    6.0000   19.0000    0.0027         0
    3.0000    3.0000   36.0000    0.0027         0
         0         0  120.0000    0.7900         0
         0   40.0000    4.0000    0.7014         0
   40.0000   40.0000  120.0000    0.7014         0
   15.0000   15.0000    2.0000    0.4240         0
   12.0000   12.0000   10.0000    0.2811         0
    9.0000    9.0000   18.0000    0.2811         0
    6.0000    6.0000   32.0000    0.0027         0
    3.0000    3.0000   72.0000    0.0027         0
         0         0         0    0.7900         0


diver_cost =   292


gas_cost   =   215.9744


total_cost =   507.9744
```

```
>> optimize_dive(5)

                                          Best         Max         Stall
Generation   Func-count          f(x)     Constraint  Generations
    1           25250         506.701            0        0
    2           50000         506.692            0        0
    3           74750         506.691            0        0
    4           99500         506.678            0        0
    5          124250         506.677            0        0
    6          149000         506.677            0        0
    7          173750         506.676            0        0
    8          198500         506.676            0        1
    9          223250         506.676            0        0
   10          280775         506.676            0        0
   11          364900         506.675            0        0

Optimization  terminated:  average  change  in  the  fitness  value
less  than options.  Function  Tolerance and  constraint  violation
is less than options.

   d_profile =

         0   40.0000    4.0000    0.7013         0
   40.0000   40.0000  120.0000    0.7013         0
   15.0000   15.0000    2.0000    0.4417         0
   12.0000   12.0000   10.0000    0.2831         0
    9.0000    9.0000   13.0000    0.1579         0
    6.0000    6.0000   19.0000    0.0020         0
    3.0000    3.0000   36.0000    0.0020         0
         0         0  120.0000    0.7900         0
         0   40.0000    4.0000    0.7013         0
   40.0000   40.0000  120.0000    0.7013         0
   15.0000   15.0000    2.0000    0.4417         0
   12.0000   12.0000   10.0000    0.2831         0
    9.0000    9.0000   16.0000    0.1579         0
    6.0000    6.0000   32.0000    0.0020         0
    3.0000    3.0000   71.0000    0.0020         0
         0         0         0    0.7900         0


diver_cost =   289.5000


gas_cost   =   217.1752


total_cost =   506.6752
```

BIOGRAPHICAL SKETCH

Mert Ünal was graduated from Saint Benoit French High School located in Istanbul. He later graduated from Galatasaray University department of Industrial Engineering along with minor program certificate from Galatasaray University Department of Business.