Research Paper

# A Simulation Model of the World Underwater Federation's (CMAS) Sustainable High-Quality Training System

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**Abstract**

For generations of scuba divers, the *World Underwater Federation (CMAS)* has sustainably maintained an effective training and certification system – despite a continuous flux of experienced people leaving and inexperienced beginners entering the organization. This paper focuses on analyzing the structure of the training system as it is described in the *CMAS* standards. It presents a qualitative Causal-Loop-Diagram illustrating the feedback structure, as well as a quantitative stock-and-flow simulation model replicating the observed behavior by implementing this feedback structure. Running the simulation model with informed assumptions as data suggests a rather simple policy to be effective: The number of *Instructor Trainers* must be maintained at a level, so that they are capable of maintaining the number of *Instructors* at a level to provide the amount of training and certification demanded for by *Beginners* and *Divers*. A population without any *Instructor Trainers* is not able to train and certify new *Instructors* itself and will – without intervention – deteriorate with time. The structure suggests a generalization to be further inquired: The critical elements for maintaining a high-quality training system for a certain skill sustainably are neither people who have mastered the particular skill nor people who teach it, but rather people who have mastered the skill and teach people who have already mastered the skill how to teach it to others.

## 1 Introduction and Motivation

For generations of scuba divers, the *World Underwater Federation (CMAS)* has sustainably maintained an effective training and certification system – despite a continuous flux of experienced people leaving and inexperienced beginners entering the organization.

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The work presented here has been conducted as part of a master's thesis in Organization Development, addressing several different, but highly related and connected aspects (Papesch 2024). Among them being:

a) the peculiarities that make scuba diving a special case to consider;
b) how these peculiarities support the evolution of the *CMAS*' organizational learning culture; and
c) modeling the structure of the *CMAS* training system focusing on how sustainability is achieved.

This paper focuses only on aspect c) – providing a model with a structural explanation of how sustainability is achieved – with the intention of making relevant structural elements transferable to contexts other than scuba diving. While aspects a) and b) are not treated in this paper, awareness that structural elements alone are not sufficient to achieve sustainability must not be ignored.

This paper follows the modeling process as described by Sterman (2000, Chap. 3). In this context, this section sets the stage by stating the goal of the system explicitly, followed by the problem statement for the model, and the relevant time horizon. The reference mode for expected and observed behavior is sketched. The formulation of a dynamic hypothesis in form of a qualitative Causal-Loop-Diagram and a quantitative Stock-and-Flow simulation model are treated later on in dedicated sections.

**Goal.** Safety is crucial in scuba diving. The goal of the training system is to ensure a large share of scuba divers who are well qualified to perform the activity in a safe manner. To achieve this goal, training of high-quality is offered.

**Problem Statement.** There are countless examples where organizations' capabilities to maintain a high-quality of training deteriorate when experienced members leave. If the timeframe is long enough, there is a continuous flux of experienced people leaving and inexperienced people entering the organization. Over the decades, the *CMAS* training system has proven its capability of maintaining the share of scuba divers who are well qualified to perform the activity in a safe manner at a high level for generations of scuba divers. How can this capability be (structurally) explained and successfully replicated?

**Time Horizon.** It is safe for people to start scuba diving when they are teenagers. They can stay active until they are in their seventies. Based on these extreme limits, a scuba diving career may span well over 50 years. To achieve the highest qualification level, it takes between 10 and 20 years. For this problem, the focus is on the point in time when people leave the organization – usually at the end of their career. The time horizon is chosen to be 100 years, which is long enough to capture this effect and the consequences resulting from it. The duration of qualifications varies from a few days for entry-level certifications to multiple years to achieve senior levels. One year is an adequate time resolution.[1]

**Reference Mode.** First-hand measures for the safe practice when scuba diving would need to take into account the number of active divers and the number of safety-related incidents. However, the way the problem is framed, safety is considered achieved as long as the reputation of the *CMAS* for ensuring that certified scuba divers are appropriately trained to perform the activity within their capabilities without risking harming themselves or others. This has been the case without interruption since the *CMAS* was founded in 1959. Under these assumptions, the share of certified divers in a given population represents the capability of the training system. Fig. 1 shows the observed and desired behavior for the *CMAS* training system with a solid green line. The dashed red line, on the other hand, shows the expected behavior of a deterioration of the number of certified divers when experienced divers leave the organization beginning at time $t_1$.

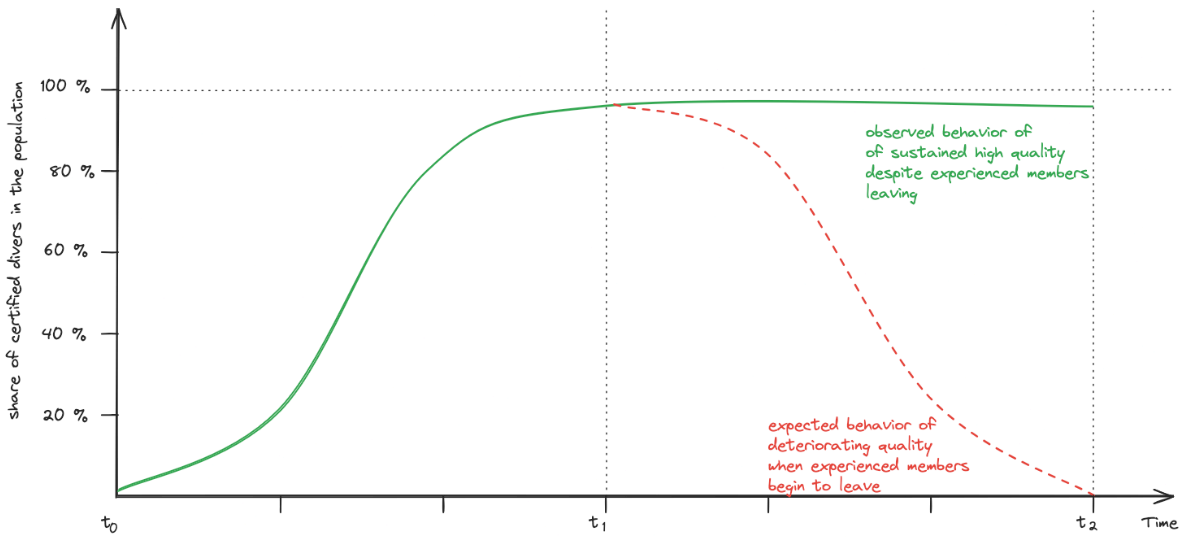


Figure 1: *Reference Mode* sketched to show expected and observed behavior of the share of certified divers in a population. (Source: own Figure).

The remainder of this paper is organized as follows. Section 2 introduces the *World Underwater Federation (CMAS)* as an organization and describes its established, high-quality training system. The formulation of a dynamic hypothesis follows in two steps: a qualitative Causal-Loop-Diagram is presented in Section 3; a Stock-and-Flow simulation model in Section 4. Section 5 describes the testing of the simulation model and presents simulation results. Section 6 addresses both implementation details and limitations of the current state of the model. Finally, Section 7 summarizes the presented and provides an outlook on possible future work.

[1] A sufficiently small DT of 1/16 accommodates for shorter cycles on a monthly basis.

## 2 Introducing the World Underwater Federation (CMAS) and its Training System

The *World Underwater Federation* (*Confédération Mondiale des Activités Subaquatiques – CMAS*) was founded in 1959. The scuba diving pioneer Captain Jacques-Yves Cousteau was elected the first president (CMAS 2025b). Meanwhile, the generation of founders has been replaced by successors, having created the situation this paper sets out to study.

*CMAS* is not the only entity providing widely recognized scuba diving training and certification. However, it is a non-profit organization that explicitly aims to provide high-quality training with a focus on safe diving.[2]

The following analysis is based on publicly available documents[3] created and maintained by the *CMAS*. Verbatim passages are intended to convey the overall mindset created by form and wording. It should become clear that the resulting structure is by no means coincidental but clearly the result of deliberation.

CMAS (2024b, Article 1) defines its identity and objectives as follows:

> 1. The World Underwater Federation (CMAS in abbreviation) is the association of national underwater federations.
> 2. The CMAS is an international, non-governmental, non-profit-making organization.
>
> (...)
>
> 5. The objectives of the CMAS are:
>    a. To direct, develop and regulate underwater activities and underwater sports, under all forms, worldwide;
>    b. to develop and encourage the understanding and preservation of the underwater world;
>    c. To promote underwater activities in all countries and at all levels;
>    d. To organize for all underwater sport disciplines, world championships and sport events for which CMAS shall have the sole ownership and rights;
>    e. To organize events, fairs, exhibitions regarding the underwater world;
>    f. To promote or carry out scientific activities or initiatives of any kind;
>    g. To encourage friendship between all members of the underwater activities world and promote sportsmanship and fair play;
>    h. To represent the underwater sport disciplines and defend its interests before the International Olympic Committee and all national and international authorities;
>    i. To cooperate with the International Olympic Committee, the WADA—World Anti-Doping Agency and all national and international sport authorities and organizations in order to achieve its objectives.

Defining, implementing, and maintaining the training system falls within the responsibility of the *Technical Committee*(CMAS 2025a):

[2] The author holds a *CMAS Instructor** certification issued by *Verband Europäischer Sporttaucher*.
[3] Registration and login are required.

> MISSION OF THE TECHNICAL COMMITTEE
> The main focus of the T.C. is providing the CMAS members with safe diving. This is achieved through promoting world class standards for all aspects of Scuba Diving and ensuring adherence of them by member federations and dive providers.
>
> GOAL AND OBJECTIVE
> The focus of the CMAS TC is providing the CMAS federation with guidelines for safe diving, education standards, quality control, teaching material and help starting with CMAS training. This is achieved through promoting world class standards for all aspects of Scuba Diving and ensuring adherence of them by member federations and dive providers.

CMAS (2024c, 3.1, p. 13) explicitly states, that "although the sport of underwater diving is safe, it is not a risk-free activity." This acknowledgement effectively establishes the necessity for a high-quality training system, which is emphasized (CMAS 2024c, p. 14):

> QUALITY DIVER EDUCATION AND TRAINING
>
> THE CMAS RECOGNISES:
>
> – That quality diver education and training is the key to both diving safety and the development of competent divers.
>
> THE CMAS THEREFORE UNDERTAKES:
>
> – To develop Diver Training Standards that will promote quality diver education and training;
> – To develop diver training programmes that are not coupled to prescribed time periods of instruction but which are coupled to the required performance of the participant.
> – To train CMAS Instructors and Dive Leaders to a professional standard;
> – To ensure that our CMAS Instructors and Dive Leaders maintain the highest standard of care to promote safety and sound customer relations;
> – To ensure that theoretical instruction is provided under the direct supervision of a certified CMAS Instructor;
> – To ensure that confined and open water instruction is provided under the direct supervision of a certified CMAS Instructor;
> – To ensure that the assessment of a diver's knowledge and skills is undertaken by a certified CMAS Instructor;
> – To ensure that CMAS Instructors are only assisted by certified CMAS Assistants or Dive Leaders that work under the supervision of a CMAS Instructor.

The *CMAS* training system differentiates 4 groups of levels, which are further divided into altogether 10 levels[4], which are further detailed in Tbl. 1:

**Beginners**
: have not completed training yet and may engage in scuba diving only when accompanied by an *Instructor*;

**Divers**
: have completed training and are certified to dive within the limits of their attained certification;

[4] The exact number of levels may vary within federations. However, for the purpose of this paper, this is not a limitation.

**Instructors**
: are experienced divers who have completed instructor training and certification and may conduct instruction for *Beginners* and *Divers*; and

**Instructor Trainers**
: are experienced *Instructors* who have completed training and certification as *Instructor Trainer* and may conduct instruction for *Instructors*.

Table 1: Overview of the competence levels of the *CMAS* training system. The *Instructor Assistant* level is an intermediate one that may be assumed by experienced *Divers**** contractually without further training. (Sources: cf. CMAS (2023e), CMAS (2023a), CMAS (2023f), CMAS (2023c), CMAS (2023b), CMAS (2023g), CMAS (2023d), and CMAS (2024a)).

| Competence level | Has been instructed by | May perform instruction for |
|---|---|---|
| **Beginners** may dive only when accompanied by an instructor | | |
| *Try-A-Dive* | – | |
| *Beginner* | *Instructor** | |
| **Divers** may dive together in groups, according to their competence level | | |
| *Diver** | *Instructor** | |
| *Diver*** | *Instructor*** | |
| *Diver**** | *Instructor*** | |
| **Instructors** perform training for beginners and divers | | |
| *Instructor Assistant* | *Instructor**** | (under supervision of *Instructor****) |
| *Instructor** | *Instructor**** | *Try-a-Dive* and *Beginner* |
| *Instructor*** | *Instructor**** | *Diver** and *Diver*** |
| **Instructor Trainers** perform training for instructors | | |
| *Instructor**** | *Instructor**** | *Instructor Assistant*, *Instructor** and *Instructor*** |
| **Staff Instructors** oversee Instructor certifications | | |
| *Instructor***** | – | |

*CMAS* differentiates between *diving* and *training*. When *diving*, a group of people enjoy a recreational activity within the limits of their respective certifications. During *training*, on the other hand, an instructor organizes a course to transfer knowledge and skills.

During any dive, problems may arise that need to be addressed and fixed immediately or require assistance from others. Safety commands that there is a minimum amount of experience present when a group of people enjoy *diving*. The necessary experience has to be acquired by *training* and *diving*.

*Divers** are trained to be capable of taking care of themselves under normal circumstances, but might need assistance from a more experienced *Diver**** from time to time.

*Divers*** are trained to be capable of taking care of themselves under all circumstances within the limits of their certification and may engage in diving autonomously with other *Divers**.*

*Divers**** are trained to be capable of taking care of themselves under all circumstances, while at the same time providing assistance to a *Diver**, if necessary.

Inexperienced *Instructors** may instruct *Beginners* to become *Divers**. More experienced *Instructors*** may instruct *Divers** to become *Divers*** and later *Divers****.

At first sight, this might look counterintuitive. Teaching *Beginners*, who have no experience at all, is harder than teaching *Divers** who are already familiar with the activity, to elevate their skills. Why, then, should inexperienced *Instructors** be assigned this task instead of their more experienced colleagues? There are three things to consider:

a) *Instructors** need to gain experience. Instructing *Beginners* will provide them with ample opportunities to do so. Later in their career, as *Instructor*** they will benefit from having done so.
b) Inexperienced people are prone to make mistakes. The criticality of an inexperienced *Instructor** making a mistake during the training of a *Diver** is rather low, as a *Diver** is limited to diving accompanied by a *Diver**** who is capable of handling difficult situations.
c) However, the criticality of an *Instructor*** making a mistake during the training of a *Diver*** is potentially serious, as *Divers*** must be able to take care of themselves and might not be accompanied by someone able to assist them.

Considered together, this results in a fault-tolerant setup, which allows people to gain experience while keeping the risk of damage low.

CMAS (2024c, p. 2) has a clear intention what to achieve with its training and certification system:

> The CMAS has developed a CMAS International Diver Training Certification System that consists of Diver, Speciality Diver, Technical Diver and Leadership Diver Training Standards and which allows divers, that have been trained in accordance with the prescribed CMAS International Diver Training Standards, to have their certifications recognised throughout the world in countries that are members of the CMAS family of divers.
>
> (...)
>
> This means that the system is intended to provide international recognition of an individual diver's level of competence and experience, irrespective of where he was trained in the world.

This intentionality enables two measures to act as feedback on whether this purpose is being achieved. These measures also provide a starting point when looking for potential data to calibrate the model.

a) The development of demand for training and certification – a training system that is not accepted by customers will not increase competence.

b) The number of incidents and accidents of certified divers within or outside their certification limits. If they are diving within their limits, the quality of their training must be questioned; if they were diving outside their limits, training failed to convey respect for these limits.

Incidents and accidents cause harm to people and are, in general, legally investigated. This kind of feedback is difficult to ignore or cover up. The ultimate feedback is the recognition of the certifications and their limits by legal bodies and insurance companies. Low-quality training and too many accidents will lead to recognition being revoked.

This last point introduces another perspective and is especially interesting. On the one hand, *CMAS* aims to certify that divers have achieved a certain competence level. On the other hand, it is the behavior and the actual competence of certified divers that give the certification its credibility. Thus, the entire training and certification system can only be maintained sustainably if its quality is kept at a high level.

## 3 A qualitative Causal-Loop-Diagram illustrating the basic feedback structure of the CMAS training system

**Dynamic Hypothesis.** As described in the previous section, the *CMAS* training system comprises 10 levels in 4 groups. The structure is the same across all levels. Each group has different properties. This allows for the Causal-Loop-Diagram to focus on the 4 groups only and ignore the additional detail complexity of different levels. Fig. 2 shows the Causal-Loop-Diagram representing the qualitative dynamic hypothesis. It consists of 4 rather distinct parts:

1) Providing training;
2) Training Demand & Capacity;
3) Succession for instructors; and
4) Regeneration of the population.

With some modification, parts 1–3 share common structures for each of the 4 groups. Part 4, regeneration of the population, wraps around the other structures.

**Providing Training.** The goal of the system shall be used as the starting point: Provide all *Beginners* with the necessary training to become competent *Divers*, and later on *Instructors* and *Instructor Trainers*.

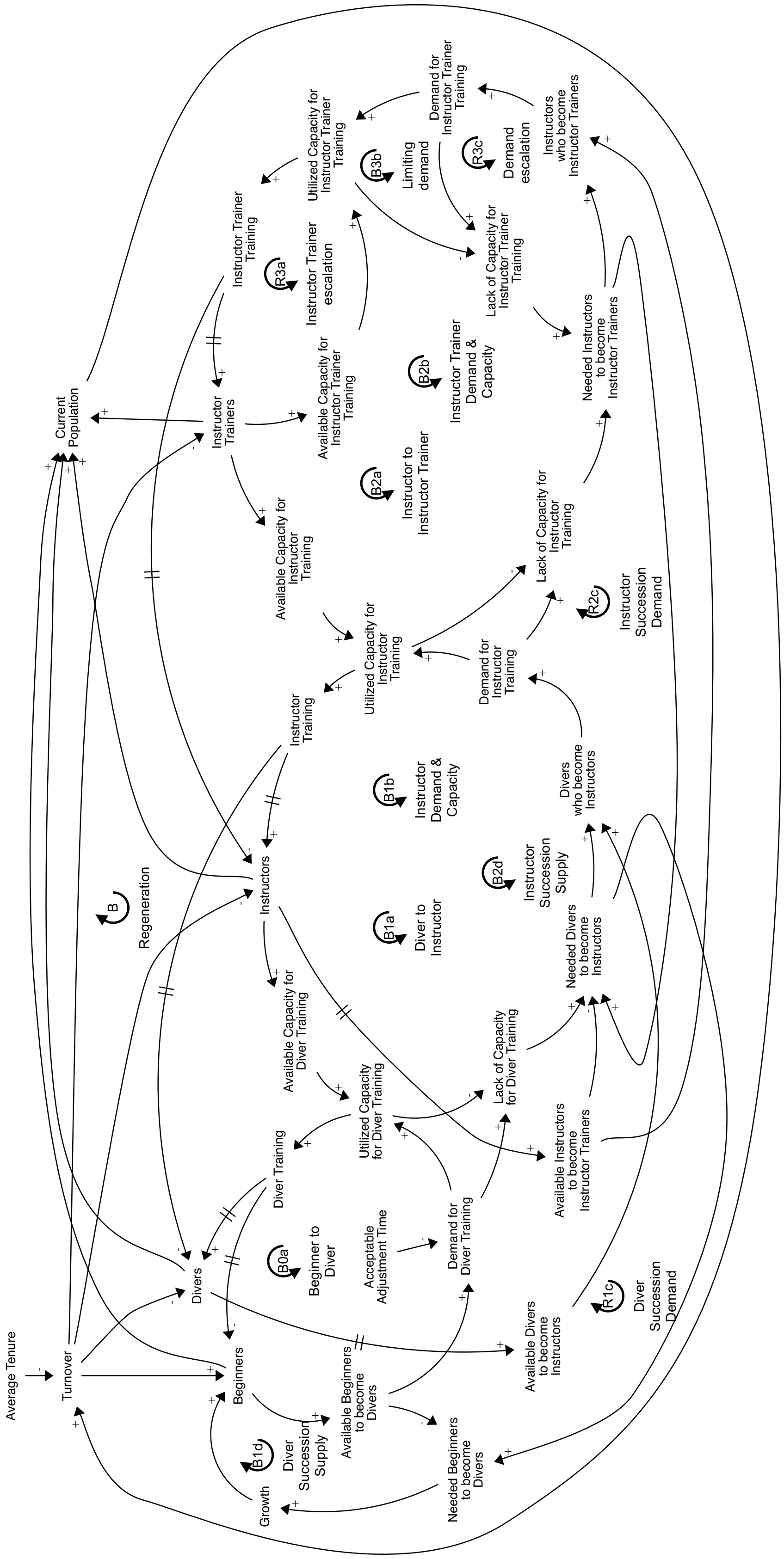


Figure 2: *Causal-Loop Diagram* as dynamic hypothesis for the *CMAS* training system (source: own figure).

Beginner to Diver (B0a)

The more Beginners there are, the higher the number of Available Beginners to become Divers, which raises the Demand for Diver Training, which increases the Utilized Capacity for Diver Training, which leads to more Diver Training, which reduces the number of Beginners (and also increases the number of Divers).

```
       Beginners
-(+)-> Available Beginners to become Divers
-(+)-> Demand for Diver Training
-(+)-> Utilized Capacity for Diver Training
-(+)-> Diver Training
-(-)-> Beginners
```

Diver to Instructor (B1a)

The more Divers there are, the higher the number of Available Divers to become Instructors, which increases the number of Divers who become Instructors and raises the Demand for Instructor Training, which increases the Utilized Capacity for Instructor Training, which yield to more Instructor Training, which reduces the number of Divers (and also increases the number of Instructors).

```
       Divers
-(+)-> Available Divers to become Instructors
-(+)-> Divers who become Instructors
-(+)-> Demand for Instructor Training
-(+)-> Utilized Capacity for Instructor Training
-(+)-> Instructor Training
-(-)-> Divers
```

Instructor to Instructor Trainer (B2a)

The more Instructors, the higher the number of Available Instructors to become Instructor Trainers, which increases the number of Instructors who become Instructor Trainers and raises the Demand for Instructor Trainer Training, which increases the Utilized Capacity for Instructor Trainer Training, yielding more Instructor Trainer Training, reducing the number of Instructors (also increasing the number of Instructor Trainers).

```
       Instructors
-(+)-> Available Instructors to become Instructor Trainers
-(+)-> Instructors who become Instructor Trainers
-(+)-> Demand for Instructor Trainer Training
-(+)-> Utilized Capacity for Instructor Trainer Training
-(+)-> Instructor Trainer Training
-(-)-> Instructors
```

**Training Demand & Capacity.** Demand for training requires available capacity for training to be utilized, possibly creating a lack of capacity. This affects *Instructors* and *Instructor Trainers*.

Instructor Demand & Capacity (B1b)

The more Instructors, the higher the Available Capacity for Diver Training, which increases the number of Utilized Capacity for Diver Training, which reduces the Lack of Capacity for Diver Training, which reduces the number of Needed Divers to become Instructors and also the number of Divers who become Instructors, which reduces the Demand for Instructor Training, and also the Utilized Capacity for Instructor Training, which yields less Instructor Training, which reduces the number of Instructors.

```
       Instructors
-(+)-> Available Capacity for Diver Training
-(+)-> Utilized Capacity for Diver Training
-(-)-> Lack of Capacity for Diver Training
-(+)-> Needed Divers to become Instructors
-(+)-> Divers who become Instructors
-(+)-> Demand for Instructor Training
-(+)-> Utilized Capacity for Instructor Training
-(+)-> Instructor Training
-(+)-> Instructors
```

Instructor Trainer Demand & Capacity (B1b)

The more Instructor Trainers there are, the higher the Available Capacity for Instructor Training, which increases the number of Utilized Capacity for Instructor Training, which reduces the Lack of Capacity for Instructor Training, which reduces the number of Needed Instructors to become Instructor Trainers and also the number of Instructors who become Instructor Trainers, which reduces the Demand for Instructor Trainer Training, and also the Utilized Capacity for Instructor Trainer Training, which yields less Instructor Trainer Training, which reduces the number of Instructor Trainers.

```
       Instructor Trainers
-(+)-> Available Capacity for Instructor Training
-(+)-> Utilized Capacity for Instructor Training
-(-)-> Lack of Capacity for Instructor Training
-(+)-> Needed Instructors to become Instructor Trainers
-(+)-> Instructors who become Instructor Trainers
-(+)-> Demand for Instructor Trainer Training
-(+)-> Utilized Capacity for Instructor Trainer Training
-(+)-> Instructor Trainer Training
-(+)-> Instructor Trainers
```

To be provided with training, *Beginners* and *Divers* depend on *Instructors*, and *Instructors* depend on *Instructor Trainers*. In both cases, the providers of training produce members of a different group. *Instructor Trainers*, however, are also able to provide training for *Instructors* to become *Instructor Trainers*, and belong to the same group as their trainers. The group of *Instructor Trainers* is able and necessary to recreate their members.

Instructor Trainer Capacity Escalation (R3a)

The more Instructor Trainers there are, the higher the Available Capacity for Instructor Training, which increases the Utilized Capacity for Instructor Training, which yields more Instructor Trainer Training, which increases the number of Instructor Trainers.

```
       Instructor Trainers
-(+)-> Available Capacity for Instructor Training
-(+)-> Utilized Capacity for Instructor Training
-(+)-> Instructor Trainer Training
-(+)-> Instructor Trainers
```

Instructor Trainer Demand Escalation (R3c)

The higher the number of Needed Instructors to become Instructor Trainers, the more Instructors who become Instructor Trainers, which increases the Demand for Instructor Trainer Training, and also the Lack of Capacity for Instructor Training, as well as the number of Needed Instructors to become Instructor Trainers.

```
       Needed Instructors to become Instructor Trainers
-(+)-> Instructors who become Instructor Trainers
-(+)-> Demand for Instructor Trainer Training
-(+)-> Lack of Capacity for Instructor Training
-(+)-> Needed Instructors to become Instructor Trainers
```

Instructor Trainer Demand Limitation (B3b)

The higher the number of Needed Instructors to become Instructor Trainers, the more Instructors who become Instructor Trainers, which increases the Demand for Instructor Trainer Training, and also the Utilized Capacity for Instructor Training, which reduces the Lack of Capacity for Instructor Training, as well as the number of Needed Instructors to become Instructor Trainers.

```
       Needed Instructors to become Instructor Trainers
-(+)-> Instructors who become Instructor Trainers
-(+)-> Demand for Instructor Trainer Training
-(+)-> Utilized Capacity for Instructor Training
-(-)-> Lack of Capacity for Instructor Training
-(+)-> Needed Instructors to become Instructor Trainers
```

**Succession.** Available capacity and demand for training need to be balanced. Neither of them should show discontinuities under normal circumstances. However, training for replacement takes time. Thus, succession for people moving up to the next level must be provided for in advance.

Instructor Succession Demand (R2c)

The higher the number of Needed Instructors to become Instructor Trainers, the higher the number of Needed Divers to become Instructors, and the number of Divers who become Instructors, which increases the Demand for Instructor Training, and also the Lack of Capacity for Instructor Training, as well as the number of Needed Instructors to become Instructor Trainers.

```
       Needed Instructors to become Instructor Trainers
-(+)-> Needed Divers to become Instructors
-(+)-> Divers who become Instructors
-(+)-> Demand for Instructor Training
-(+)-> Lack of Capacity for Instructor Training
-(+)-> Needed Instructors to become Instructor Trainers
```

Instructor Succession Supply (B2d)

The more Instructors, the higher the number of Available Instructors to become Instructor Trainers, the lower the number of Needed Divers to become Instructors, and the number of Divers who become Instructors, which decreases the Demand for Instructor Training, and also the Utilized Capacity for Instructor Training, which leads to less Instructor Training, and fewer Instructors.

```
       Instructors
-(+)-> Available Instructors to become Instructor Trainers
-(-)-> Needed Divers to become Instructors
-(+)-> Divers who become Instructors
-(+)-> Demand for Instructor Training
-(+)-> Utilized Capacity for Instructor Training
-(+)-> Instructor Training
-(+)-> Instructors
```

Diver Succession Demand (R1c)

The higher the number of Needed Divers to become Instructor, the higher the number of Needed Beginners to become Divers, which increases Growth, to increase the number of Beginners, and the number of Available Beginners to become Divers, which increases the Demand for Diver Training, and also the Lack of Capacity for Diver Training, as well as the number of Needed Divers to become Instructors.

```
       Needed Divers to become Instructors
-(+)-> Needed Beginners to become Divers
-(+)-> Growth
-(+)-> Beginners
-(+)-> Available Beginners to become Divers
-(+)-> Demand for Diver Training
-(+)-> Lack of Capacity for Diver Training
-(+)-> Needed Divers to become Instructors
```

Diver Succession Supply (B1d)

The higher the number of Needed Beginners to become Divers, the more Growth, and more Beginners, as well as Available Beginners to become Divers, which reduce the number of Needed Beginners to become Divers.

```
       Needed Beginners to become Divers
-(+)-> Growth
-(+)-> Beginners
-(+)-> Available Beginners to become Divers
-(-)-> Needed Beginners to become Divers
```

**Regeneration.** The timeframe chosen exceeds the maximum longest possible career. *Divers*, *Instructors*, and *Instructor Trainers*, will eventually retire from the system. To keep the population stable, those will be replaced by *Beginners* in this scenario.

Again, training for replacement takes time, and succession for people retiring must also be provided for in advance.

Regeneration I (Bg)

The larger the Current Population, the higher Turnover, the fewer Divers, Instructors, and Instructor Trainers, and thus the smaller the Current Population.

```
       Current Population
-(+)-> Turnover
-(-)-> { Divers, Instructors, Instructor Trainers }
-(+)-> Current Population
```

Regeneration II (Rg)

The larger the Current Population, the higher Turnover, the more Beginners and the larger the Current Population.

```
       Current Population
-(+)-> Turnover
-(+)-> Beginners
-(+)-> Current Population
```

**Insight.** The stated goal of the training system is to ensure a large share of scuba divers who are well qualified to perform the activity in a safe manner. The dynamic hypothesis suggests that to achieve this, having enough *Instructors* is crucial. To achieve sustainability, the system must be able to produce enough *Instructors* on its own. Thus, it is necessary to have enough *Instructor Trainers* to maintain the level of *Instructors* – and also the level of *Instructor Trainers* high enough. *Instructor Trainers* are the only resources in the system who are able to reproduce themselves. This makes them the critical resource.

**Goal adjustment.** Safety is crucial in scuba diving. The goal of the training system is to ensure that there are enough *Instructor Trainers* to provide enough training and certification for *Instructors* so that every person who wants to learn how to scuba dive can be provided with high-quality training that makes them well qualified to perform the activity in a safe manner.

## 4 A quantitative Stock-and-Flow model of the CMAS training system

**Simulation Model.**[5] The Stock-and-Flow diagram for the simulation model is shown in Fig. 3. It consists of four distinct, non-overlapping sectors: *State & Regeneration*, *Demand for Capacity*, *Available Capacity*, and *Utilizing Capacity*.

The four parts identified for the Causal-Loop-Diagram in the previous section are contained in the Stock-and-Flow model, but do not map directly to their own sectors:

1) Providing training maps to the sector *Utilizing Capacity*;
2) Training Demand & Capacity maps on two sectors, *Demand for Capacity* and *Available Capacity*;
3) Succession for instructors is an integral part of the sector *Demand for Capacity*; and
4) Regeneration of the population maps to the sector *State & Regeneration*.

**State & Regeneration**. The model simulates people entering the training system as *Beginners*, being trained as *Divers* by *Instructors*, and as *Instructors* or *Instructor Trainers* by *Instructor Trainers*. These groups are further divided into competence levels, as shown in Tbl. 1. All levels must be passed sequentially without skipping any level.

Training takes time to complete. Certifications become effective only after training has been fully completed, in a rather discrete step. There is no such thing as "half an instructor"; an instructor becomes fully qualified upon certification.[6] To accommodate for this characteristic, people are considered discrete entities. Additional stocks are introduced to accumulate *fractional* people until *whole* people are ready to proceed.

Each level is represented as a stock of people, which has exactly one inflow – from the level before – and two outflows – to the next level and out of the system. The stocks for all 10 levels form an aging chain. The inflow for the first stock comes from outside the system; the last stock has only one outflow out of the system.

All levels use the same structural logic. Using an array structure to implement the aging chain allows for the calculation of all levels to be combined in arrayed variables. This step eliminates the necessity to show redundant structures and reduces the visible share of detail complexity greatly.

To this end, one array dimension with 10 levels is created and used throughout the model. To implement the aging chain, there is one arrayed stock, Population, with two outflows out of the system and also two inflows coming from outside the system. One outflow represents attrition, the other movement to the next level. One inflow represents new people coming into

[5] The model file has been submitted as supplementary material and is available for download (Papesch 2025).
[6] This view is to be challenged in the following section.

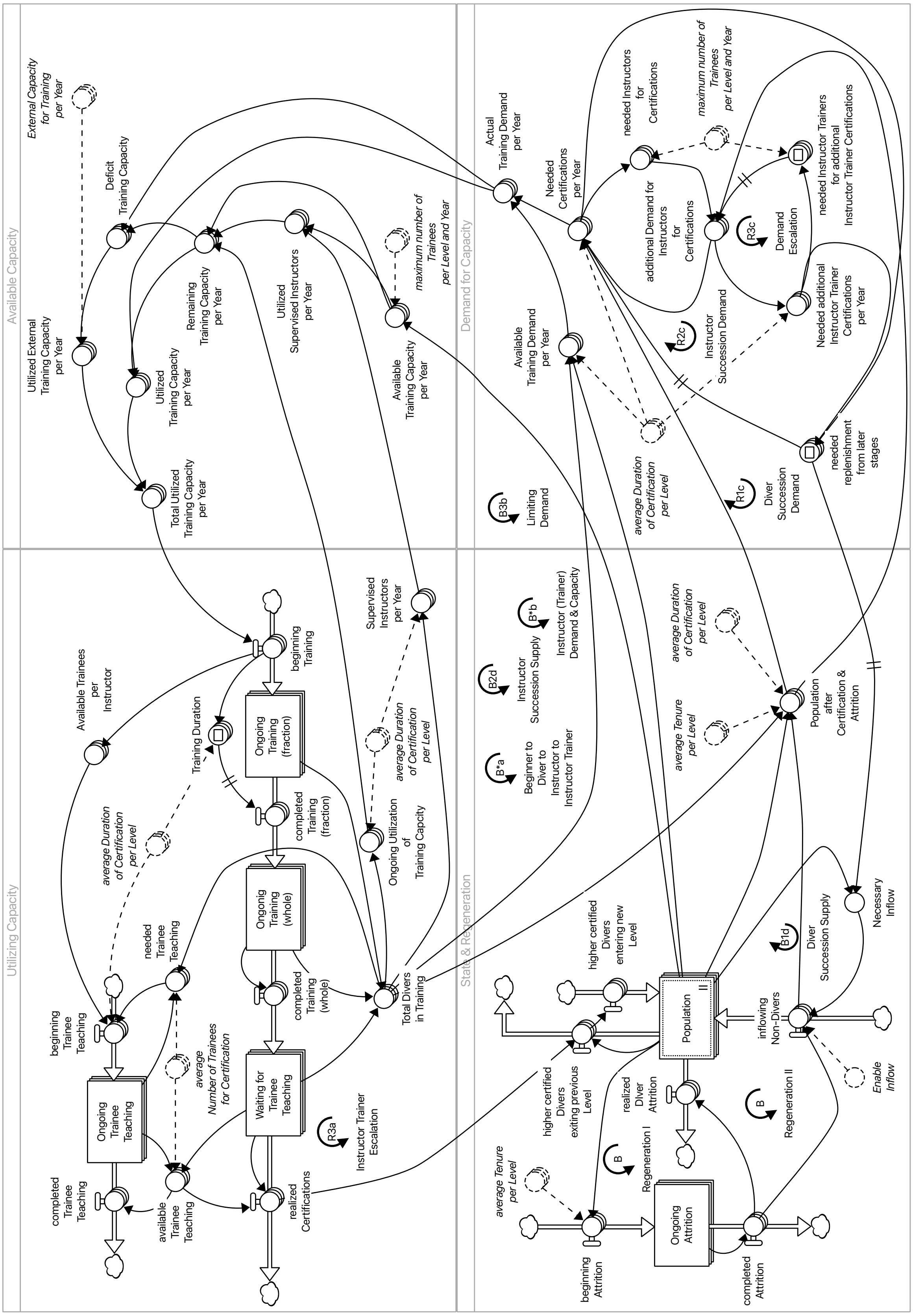


Figure 3: *Stock-and-Flow Diagram* of the simulation model for the *CMAS* training system (source: own figure).

the system, the other the movement from the previous level. The valve on the second outflow has a connection to the valve of the second inflow. The equation for each array element of the inflow is simply the value of the outflow of the previous level. The inflow for the first level is 0, as is the outflow for the last level.

This array of 10 stocks maintaining the number of people on each level represents the state of the training system. The rest of the model determines the flows of people into, through, and out of these stocks by attrition, growth, and qualification.

**Attrition.** For now, attrition is controlled by a constant exogenous parameter, attrition rate, for each level. For each level, this parameter is multiplied with the current number of people on the current level to yield the inflow into the stock, ongoing attrition. This stock accumulates fractional people until whole people can leave the stock through the outflow. The outflow from the stock ongoing attrition is connected to the attrition outflow of the stock Population and triggers the same number of whole people to leave the stock.

For this scenario, a stable population is assumed. Thus, the same number of people who leave the system through attrition will be replaced by new people entering the system at the lowest level.

**Growth.** In addition to replacing people who have left the system due to attrition, situations may arise where there is more demand for *Beginners* than are currently available. Growth, or Inflow, allows introducing additional people into the system. There is a switch variable to enable and disable inflow. When inflow is enabled, the total population is able to grow. In future scenarios, it might be interesting to see the behavior of the model with differently growing populations; or with restrictions and or delays on the necessary inflow to replace attrition.

**Qualification.** The process of qualification on all levels is the core of the model and is controlled by the number of people on each level. The flow rates for all levels are determined by the other sectors.

**Demand for Capacity.** Demand for certifications is determined based on the current state and trajectory of change based on the projected flow levels:

- How many people are there on each level?
- For the lowest level, Non-Divers, during the time it takes for them to be certified for the next level:
  - How many people will enter the level from outside the system?
  - How many people will leave the level after being certified?
- For all other levels, during the time it takes for the *previous level* to be certified and move up to the current level:

  - How many people will enter the current level after having completed certification at the previous level?
  - How many people will leave the current level after having completed certification at the current level?
  - How many people will leave the current level due to attrition?

To determine these values, the following exogenous parameters are used:

- Attrition Rate per Level, which can be derived from the average Tenure per Level
- average Duration of Certification per Level

With these values, the demand for training capacity is determined. The starting point being the intention to train and certify all available *Non-Divers* and *Beginners* to become *Divers*.

For each level:

- How many certifications are needed at this level?
- How many additional instructors are needed to provide for this number of certifications? Additionally needed instructors are certifications needed at their respective level.
- How many certifications are needed to replace those being certified for the next level? This may trickle all the way down to *Non-Divers* and increase the numbers of needed certifications for the previous levels.

To determine these values, the following exogenous parameters are used:

- maximum number of Trainees per Level and Year
- average Duration of Certification per Level

**Available Capacity.** The available capacity is determined based on the number of people currently at each level, and the overall demand adjusted to whole people.

For each level, the available capacity is determined as the minimum of these two values:

- How many certifications are needed?
- How many certifications can be provided by available instructors to available divers?

To determine these values, the following exogenous parameters are used:

- maximum number of Trainees per Level and Year

For the purpose of examining the sustainability of the training system, external resources may be made available for a specific period during the simulation. This allows to start with a population without any certified divers and to temporarily bring in a combination of instructors.

*Instructors* need to also provide a certain amount of training as part of their certification process. Thus, there is a two-way relationship between *Divers* and *Instructors*. *Instructors* are needed to provide certifications for *Divers*, and *Divers* are needed to provide certifications for *Instructors*. To determine these values, the following exogenous parameters are used:

- maximum number of Trainees per Level and Year
- average Duration of Certification per Level

**Utilizing Capacity.** While the capacity is utilized, it is being accumulated until *whole* people have completed certification. *Instructor* certifications are only complete when they have completed both; the required amount of *Diver* certification and their *Instructor* certifications have also been completed. When this is the case, certifications are realized and trigger the people to move from one level to the next.

To determine these values, the following exogenous parameters are used:

- maximum number of Trainees per Level and Year
- average Duration of Certification per Level

## 5 Testing and Simulation Results

**Testing.** The first stage of testing ensures that the model can be simulated: all variables are assigned units, and dimensional consistency is satisfied for all equations. The model can be simulated without errors. During the development, several runs have been performed using the interface shown in Fig. 4.

The interface allows adjusting the values for the following exogenous parameters for each level:

- Initial Population;
- externally available Resources;
    - Enable Project;
    - Project Beginning;
    - Project Duration;
- average Tenure per Level;
- average Duration of Certification per Level (months);
- maximum number of Trainees per Level and Year.

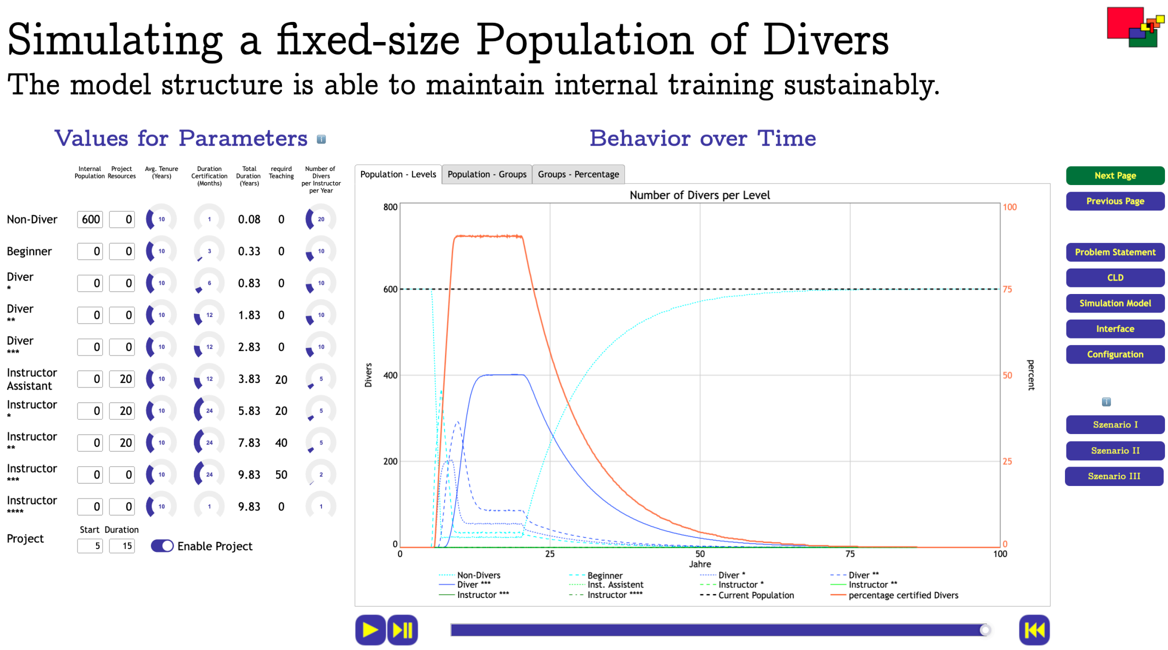


Figure 4: Screenshot of the interactive interfaces for the model which allows to adjust external parameters to control the simulation for a population of an instance of a *CMAS* training system (source: own figure).

**Simulation Results.** Two specific scenarios have been prepared to show the difference between a sustainable and a not sustainable setup. Both use an *Initial Population* of 600 *Non-Divers* and bring in temporary resources from year 5 to year 15.

The first scenario introduces 20 people of each of the following levels: *Instructor Assistant*, *Instructor**, and *Instructor***. These resources should enable the capability to certify *Divers* at all levels, but not *Instructors*. Without internal *Instructors*, the population should revert to all *Non-Divers*, after the external resources leave the system. The simulation result shown in Fig. 5 confirms this expectation.

The second scenario additionally includes 20 *Instructors****, adding the capability to train and certify internal *Instructors* and *Instructor Trainers*. If these resources are around long enough to produce at least one internal *Instructor**** the system should be able to maintain a high level of certified divers sustainably. The simulation result shown in Fig. 6 confirms this expectation as well.

**Policy design and evaluation.** The implemented policy consists of 3 components:

a) anticipating change of a level over the period of time it takes to train and certify successors;
b) determining the needed inflows to provide the capacity to perform the necessary amount of training and certifications;
c) determining the amount of capacity needed to train and certify these inflows.

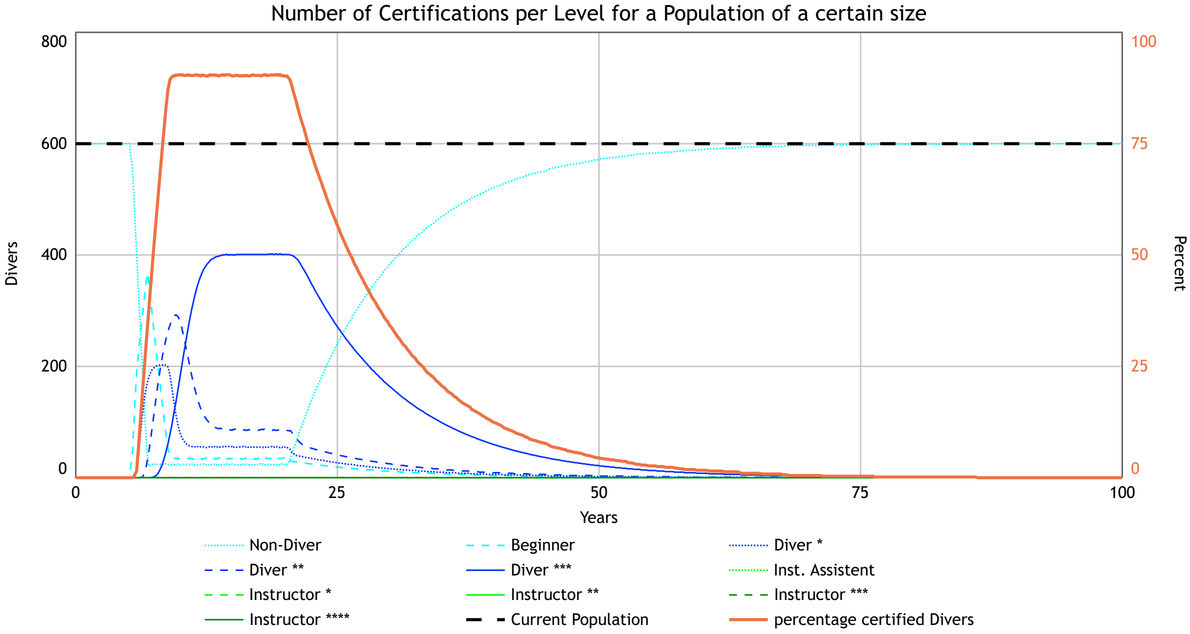


Figure 5: Simulation results for the *CMAS* training system with an initial population of 600 non-divers and 20 *Instructor Assistants*, *Instructors**, and *Instructors*** as temporary resources from year 5 to 15 (source: own figure).

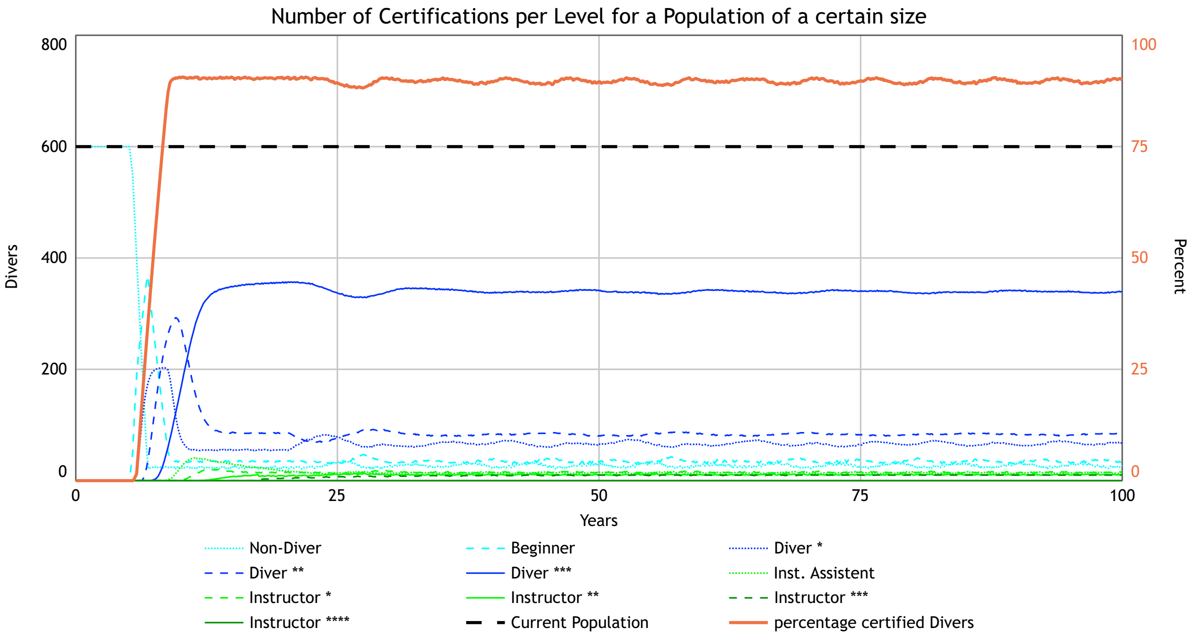


Figure 6: Simulation results for the *CMAS* training system with an initial population of 600 non-divers and 20 *Instructor Assistants*, *Instructors**, *Instructors***, and *Instructors**** as temporary resources from year 5 to 15 (source: own figure).

## 6 Implementation Details and Limitations of the Current State of the Model

**Exogenous dependencies.** The model in its current state depends on exogenous factors to determine behavior. This is considered acceptable at this stage. When going into more detail, however, feedback to these parameters can no longer be ignored, and they should be made endogenous. It should be inspected what happens when there is a big difference between demand and capacity. What happens when demand exceeds capacity by large? What happens when there is an excess of capacity? Especially the effects on average Duration of Certification per Level and average Tenure per Level should be inspected carefully.

**Multiple Organizational Units.** The current state of the model is limited to a single organization. However, the training system aims to provide a decentralized structure. *Instructor Trainers* are able to create organizational units that operate independently. This ability creates a whole new problem to be addressed.

**Economic aspects.** Although *CMAS* is a non-profit organization, there are economic factors at play. *Instructors* and *Instructor Trainers* provide professional services that can serve as the foundation for businesses in the form of dive shops. Economic aspects might introduce the need to maintain a level of certifications to cover costs, and could be an interesting extension to the current model.

**Training and Certification.** The current implementation of combines the entire delay of the training and certification process within the sector *Utilizing Capacity*. People may enter training for the next level as soon as they have finished training and certification for the current level. This serves the purpose of the problem scope. However, there is another delay for people accumulating experience on the current level before starting training for the next level. This aspect might become relevant for consideration in the context of other problem statements.

**Aging Chain with Array.** There is tension between compact representation without redundancy and illustrating identical structures with different purposes. This tension becomes tangible in the difference between the Causal-Loop-Diagram in Fig. 2 and the Stock-and-Flow model in Fig. 3. The Causal-Loop-Diagram differentiates between the four groups: *Beginners*, *Divers*, *Instructors*, and *Instructor Trainers*. These four sections are clearly visible in four distinct feedback loops. The Stock-and-Flow model needs to address 10 levels instead of only 4 groups. Having an aging chain with 10 stocks and repeating identical feedback structures creates unnecessary redundant detail complexity that is very challenging to capture and comprehend. Using an array structure to hide this detail complexity and work with a single feedback loop – simultaneously on 10 levels – greatly aides in grasping the common structure. However, in this arrangement, the subtle differences between the functions of the four groups disappear. It should be considered to apply an intermediate approach and implement the population as an aging chain consisting of 4 arrayed stocks. The groups would be explicitly visible, while the detailed levels would be hidden in the array structure.

**Discrete People.** The model tries hard to be continuous, while keeping whole people intact. The reasoning being that certifications take time to acquire and they are all or nothing. After all, there is no such thing as "half an instructor". There are similar problems, like those Coyle (1992) encountered when modeling aircraft carriers. There are also similar approaches to solve them, and that have been criticized by MacDonald (1996), who also proposed continuous alternatives. Testing the model with different values revealed that the difference to continuous values is indeed not significant – especially for large populations.

For the model to be accepted among people familiar with the underlying rules, the edge cases must hold. It must be ensured, that the certification process cannot be circumvented. *Instructors* may only perform training *after* they have completed the training and certification process *completely*. To foster acceptance, it might be helpful to create intermediate structures that detail the move from discrete to continuous people, similar to what MacDonald (1996) did for aircraft carriers.

**What did bootstrapping look like?** The training and certification system was conceived and implemented over the past roughly 75 years. It should be interesting how it came to be. How did the first *Instructor Trainers* become certified – when there were none to provide for training and certification?

**Focus on Structure.** It needs to be stated again that this model only addresses the structure that allows *CMAS* to maintain its training system sustainably. Structure alone is not sufficient to achieve sustainability on its own. Papesch (2024) identifies further aspects present in the context of *CMAS* not treated here, e. g. a strong organizational learning culture, that must not be ignored when trying to replicate this training system in a different context.

## 7 Conclusion and Outlook

This paper intends to present a model with a structural explanation of how sustainability is achieved in the *CMAS* training system – intending to make relevant structural elements transferable to contexts other than scuba diving.

Developing a Causal-Loop-Diagram and a Stock-and-Flow model created the insight that the original goal for the training system should be adjusted. The initial focus was to ensure that a large share of scuba divers are well qualified to perform the activity in a safe manner. The findings suggest that this should be adjusted to ensure that there are enough *Instructor Trainers* to provide enough training and certification for *Instructors* so that every person who wants to learn how to scuba dive can be provided with high-quality training that makes them well qualified to perform the activity in a safe manner.

From this perspective, the critical elements for maintaining a high-quality training system for a certain skill sustainably are neither people who have mastered the particular skill nor people who teach it, but rather people who have mastered the skill and teach people who have already mastered the skill how to teach it to others.

The simulation results support the hypothesis that the underlying structure does enable sustainability for the training system. Several possible improvements of and extensions to the model have been suggested in the previous section, like including multiple organizational units and economic aspects, or from a technical perspective, moving from discrete to continuous people. Acquiring historical certification data to calibrate the model or even study the bootstrapping of the training and certification process could yield interesting insights.

The identified structure should be applicable in contexts other than scuba diving. Hard to ignore feedback of low-quality has been identified as one driving force to maintain a high-quality training system. How does this relate to Train-the-Trainer approaches in other contexts? Are there any similarities, or do differences prevail? How could this structure be applied in the context of workforce development?

One downside of the structure of the *CMAS* training system is a relative high effort to set it up and a rather long delay to reach senior levels. These two properties make it unattractive for profit-based enterprises. Professional communities of practice who strive to maintain high-quality standards might benefit from adopting parts of the structure. The same holds for political parties in democratic societies, who should maintain the ability to teach their members how to teach core skills to new members.

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