Framework for planning the training sessions in triathlon

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ABSTRACT

In recent years, planning sport training sessions with computational intelligence have been studied by many authors. Most of the algorithms were used for proposing basic and advanced training plans for athletes. In a nutshell, most of the solutions focused on the individual sports disciplines, such as, for example, cycling and running. To the knowledge of the authors, few efforts were invested into planning sports training sessions in triathlon. Triathlon is considered as a popular multi-disciplinary sport consisting of three different sport disciplines. Therefore, planning the triathlon training sessions is much harder than the planning in individual sport disciplines. In this paper, we propose an initial framework for planning triathlon training sessions using Particle Swarm Optimization. Preliminary results are also shown.

CCS CONCEPTS

• **Theory of computation → Evolutionary algorithms**; • **Information systems** → *Expert systems*;

KEYWORDS

Computational Intelligence in sport, triathlon, planning training session, Particle Swarm Optimization

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1 INTRODUCTION

Planning sports training sessions and assisting athletes during their training process using sophisticated artificial intelligence methods is undergoing a huge expansion nowadays. Scientists and researchers have been studying various methods that can be used to produce efficient training plans for athletes on the one hand, and enrich the knowledge about the training process with new insights on the other. Until recently, for this purpose, they have applied the following computational intelligence methods: artificial neural networks [2, 6, 9], fuzzy logic [7], evolutionary algorithms [8] and swarm intelligence [4].

Triathlon is a multi-disciplinary sport consisting of three different sports disciplines, i.e. swimming, cycling and running. Indeed, a triathlon athlete has to finish all three disciplines consecutively in order to complete a triathlon race. Final times of particular disciplines are then summed together. However, times spent within two transitions, where athletes either finish with swimming and prepare themselves for cycling, or finish with cycling and prepare themselves for running, are also added to the final time.

Nowadays, a lot of people have started to participate in triathlons, which presents a big challenge for everyone due to their long duration and complexity of preparation for these competitions. On the other hand, this sports discipline is very healthy due to the variety of sports disciplines, where training sessions are needed for developing almost all muscle groups.

Interestingly, these competitions are also special due to the fact that a lot of triathlons are hosted in very famous destinations, which, additionally, attract competitors from all over the world. For example, the World Championships in the IRONMAN triathlon are hosted every year on Hawaii. The IRONMAN triathlon is one of the many triathlon distances existing today. Loosely speaking, there are short-, medium-, long-, and ultra-distance triathlons. Typically, newbie athletes participate in short-distance triathlons, while the more experienced prefer competitions over long-distance, e.g. IRONMAN triathlon.

A very important aspect of triathlon is also training. A training plan for triathlon is very complex, because it consists of three different sport disciplines that need, logically, to be trained together. Usually, training plans for triathlon prefer swimming training sessions before running, while biking sessions are more important than running. However, this preference order is also dependent on the characteristics of the athlete involved in training.

In this paper, we try to tackle the problem of planning the training sessions in triathlon automatically. Our intention is to develop an intelligent system or framework using Swarm Intelligence (SI) based algorithms that would be capable of collecting information about triathlon athletes, monitor them, and even plan the training sessions for them. Although some solutions exist that are capable

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of planning sports training sessions for athletes in particular sports disciplines and based on our best knowledge, this is the first solution that allows planning sport training sessions for a multi-discipline sport. Overall, the main contributions in this paper are threefold:

- to propose a framework for planning training sessions in triathlons,
- to present the planning training sessions in triathlon as an optimization problem,
- to conduct the planning training sessions in triathlon using existing triathlon activities.

The organization of the remainder of this paper is as follows. Related work is discussed in Section 2. In Section 3, the proposed framework for generating training sessions in triathlon is presented. Experiments and results are subjects of Section 4. The paper concludes with Section 5, where the performed work is summarized and directions for the future are outlined.

2 RELATED WORK

Planning the training sessions for individual sport disciplines with Evolutionary Algorithms (EAs) and SI-based algorithms were realized in some studies in the past years. Interestingly, it is worth mentioning that this research area is pretty new. However, recent trends show that more and more solutions are proposed each year.

The authors in the paper [8] explored a usage of EAs (i.e., Differential Evolution (DE), and Covariance Matrix Adaptation Evolution Strategy (CMA-ES)) for generation of training plans in order to achieve a given fitness goal. These solutions are also able to handle constraints such as, for example, maximal training loads. On the other hand, Fister et al. [4] compared various stochastic nature-inspired population-based algorithms for planning the sport training sessions based on existing sports activities. Results revealed that the Bat Algorithm (BA) is a more appropriate tool when comparing with the other algorithms, like Particle Swarm Optimization (PSO), and DE.

On the contrary, paper [1] investigated an assumption whether there is a possibility to generate pre-season training plans for Australian footballers using optimisation software. Moreover, Adaptive PSO in [5], using ϵ-constraint methods, was applied to formulate a tool for generation of a practical training plan in cycling that improves athletic performance substantially by satisfying essential physiological constraints.

3 PROPOSED FRAMEWORK

Triathlon is a very complex sport discipline, where athletes must be fully focused on simultaneous development of their psycho-physical performances during the specific sports training period. Because of the three different sports, athletes need to perform more training sessions than those who train for single disciplines only. Additionally, triathlon athletes have to train very systematically in order to achieve desired goals in each of the three disciplines. On the other hand, they do not overdo training in order to avoid injuries.

Due to the complexity of triathlon, planning the triathlon sessions in triathlons can be developed as a framework consisting of the following processes:

- data collection,
- planning the training sessions, and
- evaluation of the training plan.

In the remainder of the paper, the mentioned processes are described in detail.

3.1 Data collection

Data collection refers to a process of training plan realization, where data obtained after a finished sport training session are typically collected by the sports trainers. Usually, these data are referred to a particular performance achieved by an athlete during the training session. In earlier times, these data were tracked manually by trainers. Moreover, the data were also archived in paper form, and later compared with performances as achieved in previous training periods. Nowadays, a lot of athletes use smart watches and smart phones for tracking their sport activities automatically. These aids allow them to see parameters about particular sports activities in real-time.

Typically, the parameters capture measured values obtained after performed sports activities, like duration, distance, average speed, burned calories, and so on. These values can be uploaded easily on various computer platforms on the Internet and allow archiving, as well as deeper analysis of the performed sports activities. In contrast to cycling and running, tracking the training sessions in swimming is a little bit harder, since the majority of the classical equipment is not supported for tracking the parameters occurring when swimming.

In a nutshell, test data for current study were obtained from two sources, as follows:

- data referring to training sessions in swimming were obtained according to athlete's notes manually,
- data referring to training sessions in cycling and running were obtained from smart watches automatically.

Obviously, both data sources were assembled in the same collection that was saved onto the server in this study.

3.2 Planning the training sessions

The purpose of planning the training sessions in triathlon is to generate three training plans in different triathlon sports disciplines by considering the existing collection of sports activities that is the result of the data collection process. Indeed, the planning is presented as an optimization problem, where the task of the optimization algorithm is to maximize a proposed value of the TRIMP training load indicator. The TRIMP training load indicator is expressed mathematically as:

$$\mathrm{TRIMP} = TD \cdot HR, \tag{1}$$

where TD denotes duration of training in minutes, and HR the average heart rate in beats per minute (bpm).

Most of the nature-inspired algorithms are appropriate for this purpose. However, the PSO was selected in our study due to its simplicity and effectiveness on small-scale problems. The PSO is an SI-based algorithm introduced by Eberhart and Kenney [3] that was inspired by the social behavior of animals living in swarms. It is a stochastic nature-inspired population-based algorithm that operates on a population (called swarm) of individuals (called particles).

Additionally, the algorithm maintains the personal best for each particle $\mathbf{p}_i$ and the population global best $\mathbf{g}$. Each particle is determined with a pair of real-valued vectors representing its position $\mathbf{x}_i$ and velocity $\mathbf{v}_i$. Indeed, the velocity and position of particles are updated according to the following mathematical equations:

$$\mathbf{v}_i^{(t+1)} = w \cdot \mathbf{v}_i^{(t)} + c_1 \cdot rand_1 \cdot (\mathbf{x}_{best} - \mathbf{x}_i^{(t)}) + c_2 \cdot rand_2 \cdot (\mathbf{p}_i^{(t)} - x_i^{(t)}), \tag{2}$$

$$\mathbf{x}_i^{(t+1)} = \mathbf{x}_i^{(t)} + \mathbf{v}_i^{(t+1)}, \tag{3}$$

for $i = 1, \ldots, NP$, where NP represents the number of particles in a swarm, $rand_1$ and $rand_2$ are random numbers drawn from uniform distribution in the range $[0.0, 1.0]$, inertia weight w is used for controlling the velocity, while constants c_1 and c_2 define the strength of attraction to the global best position and the corresponding personal best position.

Thus, particles are moved through the search space towards the current best in each generation. During this motion, it is expected that the new more promising regions of the search space are discovered. The quality of solutions is evaluated in the sense of the fitness function, where the best particle replaces the current best in the population. The pseudo-code of the basic PSO algorithm is presented in Algorithm 1.

Algorithm 1 Pseudocode of the basic PSO algorithm

Input: PSO population of particles $\mathbf{x}_i = (x_{i1}, \ldots, x_{iD})^T$ for $i = 1 \ldots NP$, MAX_FE.
Output: The best solution $\mathbf{x}_{best}$ and its corresponding value $f_{min} = \min(f(\mathbf{x}_i))$.

```
init_particles;
eval = 0;
while termination_condition_not_meet do
    for i = 1 to Np do
        f_i = evaluate_the_new_solution(x_i);
        eval = eval + 1;
        if f_i ≤ pBest_i then
            p_i = x_i; // save the local best solution
            pBest_i = f_i;
        end if
        if f_i ≤ f_min then
            x_best = x_i; // save the global best solution
            f_min = f_i;
        end if
        x_i = generate_new_solution(x_i);
    end for
end while
```

Modified PSO for planning the training sessions in triathlon. Solutions in modified PSO are represented as real-valued vectors:

$$\mathbf{x}_i^{(t)} = (x_{i,1}^{(t)}, \ldots, x_{i,d}^{(t)}, x_{i,d+1}^{(t)}, x_{i,d+2}^{(t)}), \tag{4}$$

where $x_{i,j}^{(t)} \in [0,1]$ for $i = 1, \ldots, NP$ and $j = 1, \ldots, d$ encodes the ID_k of a training session from a particular archive A_k, $x_{i,d+1}^{(t)}$ determines the first and $x_{i,d+2}^{(t)}$ the second cut point, NP is the population size, d is the dimension of the problem, and t is the generation counter. The ID_k is decoded into the training session according to the following equation:

$$ID_k = \lfloor x_{i,j}^{(t)} \cdot |A_k| \rfloor + 1, \tag{5}$$

for $k \in \mathcal{D}$, where the set of triathlon disciplines are defined as $\mathcal{D} = \{swim, cycle, run\}$.

The purpose of the cut points is to determine which parts of the vector belong to the training sessions in swimming, cycling or running. In other words, the first cut point q_1 determines the number of training days for swimming, the difference between both cutting points $q_2 - q_1$ the number of training days for cycling, while the remaining training days to the end of training period, expressed as $d - q_2$, are devoted to running.

The following objectives need to be satisfied by determining both the cutting points, as follows:

$$\begin{aligned} 3 \cdot q_{\min} &\leq d, \\ q_1 &\geq q_{\min}, \\ q_2 - q_1 &\geq q_{\min}, \\ d - q_2 &\geq q_{\min}, \end{aligned} \tag{6}$$

where $q_{\min}$ denotes the minimum training days of a specific sports discipline. Both the cut points are expressed according to the following equations:

$$\begin{aligned} q_1 &= q_{\min} + \lfloor x_{i,d} \cdot |I_1| \rfloor + 1, \text{ and} \\ q_2 &= q_1 + \lfloor x_{i,d+1} \cdot (d - |I_2|) \rfloor + 1, \end{aligned} \tag{7}$$

where $|I_1| = d - 3 \cdot q_{\min}$ and $|I_1| = d - q_1 - 2 \cdot q_{\min}$. Thus, the mentioned equation ensures that $q_1 \in [q_{\min}, d - 2 \cdot q_{\min}]$ and $q_2 \in [2 \cdot q_{\min}, d - q_{\min}]$.

The fitness function of the problem is expressed as a weighted sum of TRIMP load indicator values obtained by finishing the sports training sessions in an appropriate sports discipline, in other words:

$$f(\mathbf{x}_i) = \max \sum_{k \in \mathcal{D}} w_k \cdot TRIMP_k(\mathbf{x}_i), \tag{8}$$

where w_k for $k \in \mathcal{D}$ denotes the importance of the sports discipline in the training, and function $TRIMP_k(\mathbf{x}_i)$ is a proposed training load indicator in a particular sports discipline, and the proposed training load indicator is calculated as:

$$TRIMP_k(\mathbf{x}_i) = \sum_{day=1}^{d} TRIMP(ID_k), \quad \text{for } k \in \mathcal{D}, \tag{9}$$

where day denotes training days in the period of duration d, and function $TRIMP(ID_k)$ determines the TRIMP training load indicator in the particular sports discipline. The task of the optimization is to maximize the value of weighted sum in Eq. (8).

For sports training in triathlon, it holds that the amount of training is not the same for all training disciplines in triathlon. Thus, the swimming training is, typically, preferred by the sports trainers, because this kind of training demands the biggest effort for the athlete. On the other hand, maintaining the higher form of the athlete is easier in cycling. The mentioned characteristics can be captured in fitness function by introducing weights, where setting, e.g., $w_{swim} = 1.0$, $w_{run} = 0.75$, and $w_{cycle} = 0.5$, prescribes the following preference relation of importance of the sports disciplines in triathlon:

$$w_{swim} \succeq w_{run} \succeq w_{cycle}, \quad (10)$$

where the operator $' \succeq '$ denotes the relation "is better than". However, this preference relation depends on the characteristics of a specific athlete involved in sports training and is, therefore, determined by the sports trainer.

3.3 Evaluation of the training plan

The purpose of this process is to track the realization of a sports training plan in triathlon, and to evaluate the improvement of their athletes during the training period. Unfortunately, this task can only be performed just after the completion of the training period. Therefore, the evaluation of the generated training plans in triathlon was limited to commenting them by the real sports trainer in triathlon.

4 EXPERIMENTS AND RESULTS

The goal of the experimental work was to show that the PSO algorithm is suitable for planning the training sessions in triathlon. In line with this, the proposed algorithm was applied for generating the training plan in triathlon using an archive consisting of 10 basic training sessions in each sports discipline. The algorithm was developed in Python programming language.

During the experiments, the PSO for planning the sports training sessions in triathlon used parameters as illustrated in Table 1. Let us mention that only one from the performed 30 independent runs of the stochastic algorithm was examined closely because of the intention of this preliminary study to verify that the generated training plans in triathlon confirmed the expectations of the real sports trainers. Thus, the green light for future development is turned on.

Table 1: Parameter setting of the proposed PSO.

Parameter	Symbol	Value
Population size	NP	100
Dimension of the problem	d	50
Inertia weight	w	0.7298
Cognitive component	c_1	2.0
Social component	c_2	2.0
Minimum training days	$q_{\min}$	12
Weight of swimming	w_{swim}	1.0
Weight of cycling	w_{cycle}	0.5
Weight of running	w_{run}	0.75

In the remainder of the paper, the archive of basic sports activities is presented in detail, and the results are illustrated of the preliminary results of planning the sports sessions in triathlon.

4.1 Archive of basic sports activities

The motivation of this study was to generate the training plans in triathlon based on the existing sports activities. Obtaining real data about these activities in three different sports disciplines demands a huge effort.

Therefore, the archive of basic sports activities in three different sports disciplines was collected, including data obtained in cycling and running sports disciplines from a Garmin Connect application. Obviously, these data were captured with a Garmin wearable sportwatch by tracking the real sports activities. In contrast, data about sports training sessions in swimming were reproduced from notes made by the real sports trainer. Finally, a collection of 10 sports training sessions in three different sports disciplines was assembled, which, thus, presents a basis for generating the sports training plans in triathlon.

Mostly, the training sessions in swimming are the most complex, because some kind of infrastructure is needed for this sport (e.g., swimming pools, lakes, rivers etc.). On the other hand, the real sports trainer is often unavoidable in this sports discipline. Typically, there are four types of sports training sessions in swimming, as follows:

- technique,
- interval,
- recovery,
- long-distance.

Technique training sessions are devoted mostly for improving the swimming technique of an athlete. This is very important for younger and newbie athletes. However, even experienced swimmers must work on this issue. Interval swimming sessions are connected with sports activities of high intensity. Recovery swimming sessions are usually conducted after the races or some hard training sessions in other sports disciplines. Long distance swimming sessions are reflected by their long distance at lower heart rate. Indeed, similar types of training sessions also exist in the other two sports disciplines.

The archive of the basic training sessions, illustrated in Table 2, is divided according to the sports disciplines in triathlon (i.e., swimming, cycling, and running). Thus, each basic training session is determined by its ID, intensity measured by an average heart rate HR in beats per minute [bpm] and duration TD measured in minutes [min].

Table 2: Archive of the basic training sessions.

Nr.	Swimming			Cycling			Running		
	ID	HR	TD	ID	HR	TD	ID	HR	TD
1	SW-1	142	65	CY-1	125	70	RU-1	125	38
2	SW-2	141	91	CY-2	130	81	RU-2	121	40
3	SW-3	141	74	CY-3	138	120	RU-3	141	71
4	SW-4	142	65	CY-4	145	124	RU-4	138	87
5	SW-5	156	64	CY-5	143	110	RU-5	145	84
6	SW-6	141	55	CY-6	160	90	RU-6	150	65
7	SW-7	158	47	CY-7	165	119	RU-7	162	82
8	SW-8	125	38	CY-8	167	134	RU-8	167	61
9	SW-9	128	36	CY-9	172	60	RU-9	173	52
10	SW-10	128	26	CY-10	173	94	RU-10	175	40

As can be seen from the table, the basic training sessions of higher HR and shorter TD typically denote the interval training sessions (e.g., SW-7, CY-9 or RU-10). In these training sessions, the phase of maximum intensity is followed by the phase of resting. Typically, this sequence is repeated more times during the realization of the training session.

4.2 Generation of the training plan in triathlon

Actually, the training plan in triathlon consists of three particular training plans regarding each involved sports discipline. Indeed, the generated training plan determines the so-called cumulative training sessions during the training period. This means that the particular sports training sessions are not distributed according to specific days during the training period and therefore represent only the results of the first phase of generation as proposed by Fister et al. in [4].

The training plan in swimming as proposed by the PSO for generating the training plans in triathlon is presented in Table 3 that consists of five columns denoting the sequence number of rows, the swim session identifier ID, the corresponding TRIMP load indicator, the repetition of the swim training session, and the total TRIMP load indicator. As can be seen from the table, there 20 are

Table 3: Proposed training plan in swimming.

Nr.	ID	TRIMP/session	Repetition	TRIMP/period
1	SW-3	10,434	3	31,302
2	SW-4	9,230	3	27,690
3	SW-5	9,984	8	79,872
4	SW-6	7,755	3	23,265
5	SW-7	7,426	1	7,426
6	SW-8	4,750	1	4,750
7	SW-9	4,608	1	4,608
$\sum$	n/a	54,187	20	1,083,740

training sessions reserved for swimming that presents 40 % of the whole training period. Interestingly, the SW-5 training session is set in the center of gravity in the proposed training plan, because this training session occupies almost 10 % of the proposed training plan in swimming. On the other hand, this base session belongs to the more intensive between the other in the archive.

The proposed cumulative training plan in cycling is illustrated in Table 4, from which it can be observed that the training in cycling

Table 4: Proposed training plan in cycling.

Nr.	ID	TRIMP/session	Repetition	TRIMP/period
1	CY-3	16,560	1	16,560
2	CY-4	17,980	3	53,940
3	CY-5	15,730	2	31,460
4	CY-6	14,400	1	14,400
5	CY-7	19,635	1	19,635
6	CY-8	22,378	3	67,134
7	CY-10	16,262	1	16,262
$\sum$	n/a	122,945	12	1,475,340

is presented in 12 training days (or 24 % of the whole training plan). As a matter of fact, the training sessions are distributed more uniformly according to their TRIMP values. However, the CY-8 is the most often proposed training session in cycling, because it presents almost 5 % of intensity load during the whole period.

Finally, the proposed training plan in running is depicted in Table 5, from which it can be seen that the 18 training days are devoted for running (i.e, 36 % of the whole training plan). Indeed, the RU-7 training session stands out because of occurring in the plan 10-times (i.e., more than 50 % of the whole training plan in running). This means that the interval training sessions are set in the center of gravity by the training plan because of the higher intensity and the lower duration of the RU-7 training session.

Table 5: Proposed training plan in running.

Nr.	ID	TRIMP/session	Repetition	TRIMP/period
1	RU-3	10,011	1	10,011
2	RU-4	12,006	1	12,006
3	RU-5	12,180	5	60,900
4	RU-7	13,284	10	132,840
5	RU-8	10,187	1	10,187
$\sum$	n/a	57,668	18	1,038,024

4.3 Discussion

The main problem arising in generating training plans in triathlon is how to balance the TRIMP training load indicator values between all three sports disciplines. This balancing ensures that the triathlon athlete is developed evenly for all three involved disciplines. Moreover, it is well known from everyday triathlon practice that the amount of training sessions is not distributed evenly between the disciplines.

This fact is also seen transparently in Table 2, where the archives of the basic training sessions are illustrated. Thus, the majority of swimming sessions rarely overcomes the value of TRIMP $\geq 10,000$. On the other hand, cycling and running sessions satisfy this objective on the whole. Moreover, some training sessions in cycling demand even more effort (e.g., TRIMP $\geq 20,000$).

This balancing problem is solved in the proposed PSO for generating the sports sessions in triathlon by introducing weights that prescribe the preference relation between particular sports disciplines. In order to show the appropriateness of this mechanism, the analysis of summary results was performed, while the results are aggregated into Table 6.

Table 6: Analysis of the proposed training plan.

Discipline	TRIMP	Sess.	TRIMP/Sess.	Ratio	Weights
Swimming	1,083,740	20	54,187	1.00	0.30
Cycling	1,475,340	12	122,945	0.50	0.41
Running	1,038,024	18	57,668	0.75	0.29
Summary	3,597,104	50	234,800	2.25	1.00

As can be observed from the table, the majority of training sessions are proposed in swimming (column "Sess."). In the proposed training plan, the maximum load is demanded by training sessions in cycling (column "TRIMP"). Balancing load in both sports disciplines is expressed with the ratio of weights, in other words $w_{swim} : w_{cycle} = 2 : 1$. When the ratio between the total TRIMP per particular discipline by the total TRIMP of the proposed training plan is taken into consideration (column "Ratio"), it can be concluded that the training load of the swimming and running sessions is balanced, while the training load of the cycling sessions is a little bit too high.

In summary, it can be concluded that introducing the weights by fitness evaluation aids balancing the training load between all three involved disciplines in triathlon. According to the assurances of real sports trainers in triathlon, some unbalancing between sport disciplines in training plans must remain, because the cycling sessions are exposed as the most intensive according to the TRIMP measure.

5 CONCLUSION

Generating the sports training sessions in triathlon was rarely solved using a digital computer until recently. Although generating the sports sessions using a computer's power is already applied to individual sports disciplines, planning training sessions in triathlon demands a new approach, due to the presence of three different sports disciplines (i.e., swimming, cycling, and running). Therefore, this paper is focused on solving this problem by proposing the framework for generating triathlon training sessions based on the modified PSO algorithm.

Mainly, the problem of balancing the training loads between all three sports disciplines was identified as the more serious one during the development. In this paper, the problem was solved by introducing weights, with which the importance of a particular sports discipline is estimated in fitness evaluation. As a result, the fitness function was implemented as a weighted sum of training loads obtained by the particular sports disciplines. The results of the proposed framework showed that it is suitable for using in practice.

The proposed PSO algorithm for generating the training sessions in triathlon selects the particular training session from an archive consisting of 10 basic sports activities for each involved sports discipline. However, this archive is an approximation of the collection of existing sports activities that must be assembled for the specific athlete during recent seasons. Thus, using a real collection of existing sports activities would give us additional opportunities for development of the algorithm in the future. On the other hand, the PSO algorithm was employed in this preliminary study only. Therefore, a comparing the obtained results with the other nature-inspired algorithms would also be necessary in the future.

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