Representation and Matching of Team Managers: An Experimental Research

Cong Yang, Olaf Flak, and Marcin Grzegorzek

***Abstract*— The main goal of this paper is to provide an effective approach to quantify patterns of team managers so that they can be learned and compared by machines. Traditionally, team managers are analyzed and compared based on the data collected from surveys and questionnaires. Then, managers are usually represented by managerial roles/skills and analyzed semimanually by human perception. However, it causes two methodological problems: 1) managerial roles and skills are usually isolated and only indirectly related to managerial actions and 2) the perception-based methods cannot provide detailed analysis results since human perception is abstract and lacks stability. In order to solve these problems, we propose a simple but powerful manager representation method which is general enough to cover most manager types. With this, team managers can be learned and compared my machines. Particularly, we represent a manager by managerial actions with flexible feature groups to improve the expandability and description power of the proposed representation model. For manager analysis, we introduce the first matching algorithm which not only returns robust and stable manager similarities but also details the matched parts among managerial action sequences. The efficiency of the proposed methods is substantiated by comparison experiments between machines and human perception.**

***Index Terms*— Manager matching and classification, manager representation, team managers, team management automation.**

I. Introduction

FOR the purpose of improving the team work in dynamic and complex environments, research on team managers has attracted more and more attention. It is said a team and a team manager are the warp and woof of the dynamic fabric of organizations. They cannot exist without each other activated by managerial actions as a constellation of specific objectives, resources, and processes [1].

Teams in organizations are used to defined as social systems of two or more units in which team members perceive themselves and each other as collaborating on a common task [2]. For the purpose of improving the team work ability on more dynamic and complex environments [3] today, research on team work becomes more relevant [4] and has attracted a lot of attention in the past decades [3]. One common perception of those studies is that the spirit of team works are team managers [1]. A team manager can be defined as a team member: 1) who comprises influencing actions affecting the other team members; 2) who chooses objectives for the team, organizes activities to accomplish the objectives; and 3) who motivates team members to achieve the objectives and maintains cooperative relationships and teamwork to optimize collective time of work [5].

Therefore, in order to ensure a team can achieve the established goals with clear assumptions [6], it is crucial to clarify managerial actions that govern team actions [7]. Consequently, it leads to a strong need for research on managerial action analysis [8]. It has also been proved by the fact that not having conclusions of those research, and, as a result, not putting this knowledge into practice by team managers could lead to disastrous competition, conflicts, and apathy of team members [9].

Traditionally, team managers are analyzed and compared based on the data collected from surveys and questionnaires [10]. For this, team managers are usually represented by managerial roles and managerial skills which are assessed by human perception and analyzed semimanually [7], [11]. In general, this traditional approach causes two methodological problems: first, this strategy has low efficiency since the collected data are mostly loosely structured, the described managerial roles and managerial skills are usually isolated and only indirectly related to managerial actions. Second, the perception-based methods cannot provide a detailed and stable analysis result since human perception is too abstract and lacks stability.

These two methodological problems can be described by two research questions.

1) How to model a team manager in order to fully represent the characteristics of his managerial actions.
2) What kind of methods could be employed to distinguish team managers and, additionally, to label their styles of leadership.

Traditionally, the first methodological problem is addressed by the action sequence analysis which used to track the order of actions over time [12]. Those actions are usually declared by managers and then collected by questionnaires [10]. Based on that, a team manager can be represented by a data map describing the action features of, e.g., "what," "when," and "how" [13]. However, this method is not robust because some managerial actions could be ignored due to the poor

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memory and impression of team managers [14]. Moreover, this representation method has low flexibility since different managers may take different types of managerial actions. In such a case, this method is not general enough to cover most managers [13].

In order to solve this problem, we propose a general model to represent a team manager by managerial actions and their features. Specifically, a team manager is, at first, represented by an action sequence. After that, each action is modeled by action features within different feature groups. Theoretically, the proposed method of modeling can preserve both fine- and coarse-grained information of a team manager. The main reason is that, we describe each managerial action by several different action features. Moreover, the proposed method is general enough to cover most types of managers since each managerial action is represented by flexible feature groups. Finally, the proposed model can be easily adapted to online/offline managerial tools which are more and more popular among team managers.

The second methodological problem means that the team managers are commonly distinguished and labeled by human perception [7], [11] of, e.g., work results, attitudes, and values. However, there are four main disadvantages of such a method.

1) It cannot accurately measure the similarity/dissimilarity between team managers since human perception is highly abstract.
2) This method is not robust due to the instability of human perception [15], [16].
3) This method has low efficiency since the distinguishing and labeling processes are both applied manually.
4) Even if two team managers are similar to each other by human perception, it is hard to point the detailed similar/dissimilar parts among their managerial action sequences.

For this problem, we propose a method that can overcome these disadvantages. Particularly, by the action matching between team managers, the proposed method not only returns the similar parts among action sequences, but also calculates the global similarities. In order to do so, the proposed matching method integrates both local and global matching strategies. The local matching strategy allows an accurate measuring of local similarity between action blocks within action sequences while the global matching strategy calculates the overall similarity between managers based on the local similarities. In such a case, the proposed method can automatically and accurately distinguish team managers. In addition, this method can enrich the research methodology in the area of team work [17].

Built on the aforementioned analysis, the main aims of the paper are as follows.

1) To introduce a team manager representation model based on managerial actions. This model can properly cover the characteristics of different team managers.
2) To propose a team manager matching method which can be employed to calculate similarities of team managers. In order to verify the completion of these aims, we applied a bunch of experiments in which 150 volunteers were involved over 15 months. They played roles of team managers and their main task was to plan projects with online management tools. These tools can simultaneously record their managerial actions.

The main scientific contributions of this paper include the following.

1) We apply an interdisciplinary research between management activities and pattern recognition to deal with the team manager representation and matching.
2) We introduce an effective and general team manager representation method.
3) We propose the first algorithm that can accurately measure the similarity between team managers. Based on it, promising accuracy of the proposed methods is substantiated by the comparison of team manager similarities done by the algorithm and human perception.
4) In order to evaluate the effectiveness of the proposed methods, we designed and developed several online management tools to collect managerial actions represented by action features. These tools can also be extended to other management-related studies.

It should be noted that the work in the paper is motivated by our preliminary experiments in [7] and [18]. However, this paper offers substantial novel contributions beyond those of the work in [7] such as background analysis, action representation, manager similarity, platforms, and applications. We also conduct further experiments, reported in this paper, to evaluate these novel contributions and to draw new conclusions.

II. Related Work

The view of a manager has changed many times over the last hundred years. At the beginning of the scientific management age, a manager in an organization was represented by his/her functions, such as a reflective planner, an organizer, a leader, or a controller [34]. However, these approaches do not have the information of real managerial actions. Besides many other later approaches, it took 50 years to experience a significant change in the view of manager natures. Particularly, the most dominating approaches consist of two main concepts: 1) *managerial roles* that a manager should play [35], [36] and 2) *managerial skills* that a manager should have [37], [38]. Koontz and O'Donneil [39] launched a discussion on the meaning of managerial skills and 10 years later Katz proposed representation of a manager by managerial skills. He claimed that successful managers are indeed eclectic and they must possess and be skilled in technical, human, and conceptual areas of organizational life [38]. In 1973, Mintzberg concluded that a manager can be described in terms of 10 roles [40]. Due to the deep influence of these concepts among scientists and practitioners, in most publications, a manager is represented by managerial skills and managerial roles (see Table I).

Based on the survey and analysis of the published methods in Table I, we draw a conclusion that managerial skills and managerial roles as traditional theoretical concepts are sufficient to represent a team manager. However, they are still not general and robust enough to describe most types of managers. The main reason is that the concepts of managerial skills and managerial roles only illustrate what competences a

TABLE I
EXAMPLES OF PUBLISHED RESULTS ON MANAGERIAL SKILLS AND ROLES OVER LAST 50 YEARS

Year	Method	Samples	Topic	Subjects
1967	Survey	520	The nature of the skills involved in managerial jobs [19].	Managers,32 manufacturing firms, Madison Milwaukee industrial area.
1978	Survey	106	Managerial effectiveness in relations with behaviour and activities [20].	Managers, 6 companies, US.
1983	Survey	180	Importance of Mintzberg's roles and perceptions of role requirement [21].	Managers, private sector service, manufacturing firms, US.
1983	Survey	48	Relations between managerial roles and managerial skills [21].	Managers, a mid-sized manufacturing company, US.
1993	Survey	111	Managerial Mintzberg's roles of the chief information officer (CIO) [22].	Managers,the listing of Fortune 1000 companies (1991).
1999	Survey	105	Relationships,between,creativity,style and the management skills [23].	Managers and MBA students,South-eastern state universities, US.
2002	Survey	1125	Employees' emotions as measures of managerial effectiveness [24].	Middle managers, high-technology firms, US.
2004	Survey	547	Importance of Mintzberg's roles in IS managers work [25].	Managers, MIS departments, US.
2006	Obs.	4	Perception of the role of managers [26].	CEO, personal companies (market value exceeded $12 billion), US.
2011	Survey	200	Influence of the personality traits of on managerial skills [27].	Students in age from 20 to 29 years.
2014	Survey	107	Importance of each managerial role in using managerial skills [28].	MBA students.
2015	Dep.	19	Importance of values and skills of managers [29].	Senior lean managers, Dutch medium-sized companies.
2015	Survey	50	Importance of conceptual, interpersonal, technical skills of managers [30].	Agro-managers, fifty Slovak agricultural enterprises.
2015	Que.	52	Management skills of retail,companies [31].	Team leaders, retail companies.
2015	Survey	381	Environmental, organizational, and specific factors in leadership [32].	Working students at universities, US.
2015	Survey	720	Attitudes toward organizational change [33].	Middle managers, Swiss public hospitals.
2016	Survey	15000	Actions of great leaders, their activities and roles [6].	Team leaders, 300 organizations and 20 industries, 18 countries.
Obs.: Observation, Int.: Interviews, Dep.: Dephi method, Que.: Questionnaire				

manager should have and should do, respectively. They do not show what a manager really does. Built on this observation, in Section III, we represent a manager by managerial actions which are the missing point in relations between managerial skills and managerial roles. With this, the proposed representation method integrates managerial skills and managerial roles and turns them into managerial actions. Therefore, comparing to the traditional manager representation method, the proposed approach has high distinguishing power and stability. In addition, this representation method is suitable for action sequence matching in Section IV.

In Table I, we can also clearly observe that most research projects were conducted by the survey method with questionnaires. With this method, it is hard to quantitatively compare the differences between managers. In order to distinguish different types of managers, the traditional perception-based methods (Table I) are not robust since human perception could be influenced by many factors such as memory, emotions, and so on. Moreover, these methods are normally time-consuming because in many cases they are carried out manually [31] or semiautomatically [6]. To solve these problems, we propose an automatic method that can calculate the similarity between managers based on their action sequences. In addition, the partial similar/dissimilar action blocks within sequences can also be returned. With the proposed method, researchers can apply a deeper and more accurate analysis of managers and their actions. In such a case, the proposed method gives more potential research possibilities in management science. Moreover, since the proposed manager representation and matching are fully automatic methods, they can be adopted to some management applications [41]. For instance, a manager can be guided by action sequence matching with the knowledge action sequences from other managers.

III. TEAM MANAGER REPRESENTATION

Answering to the first research problem (Section I), we first introduce the relationship between managers and their actions. After that, we theoretically describe the feasibility of manager representation using actions and their features. Built on this, a mathematical model for manager representation is proposed.

A. Managers and Actions

To represent each managerial action, it is important to discuss and analyze its ontological concept: the system of organizational terms (SOTs). SOT is an original theoretical construct in which the organization performance is tracked and recorded. In order to do so, observation techniques are used along with the online management tools [42].

The ontological assumption of SOT is that every fact in the organizational reality can be represented by the organizational term [43]. The organizational term is a symbolic object which can be used as an element of the organizational reality model [44]. The organizational term is a close analogy to a physical quantity in the SI unit (length, mass, time, and so on). It is assumed that the organizational terms are abstract objects which are used to represent the facts which appear in the organizational reality. The features of the organizational term, on one hand, come from its definition and, on the another hand, derives from causal relations or occurrence relations with other organizational terms [45]. When the organizational term appears, it can be changed quantitatively, qualitatively, mereologically, and substantially [46].

The philosophical foundation of SOT is based on Wittgenstein's philosophy: facts (the only beings in the world) and their "states of facts" [47]. We extend this concept and propose that managerial actions can be organized by events and things. Facts, which are things (primal organizational terms) in the

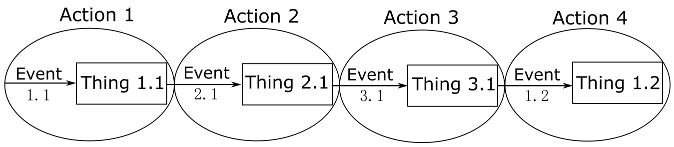

Fig. 1. Fundamental structure of actions.

organizational reality, represent resources [48]. Facts, which are events (derivative organizational terms) in the organizational reality, represent processes in the organization [49]. By the same token, the SOTs combine the resource approach and the process approach in the management science. It combines processes which effect in resources. In pairs they create managerial actions [21].

Specifically, as shown in Fig. 1, each event and thing have the label $I.J$, in which I and J represent a number and a version of a thing, respectively. Event 1.1 causes thing 1.1, which in turn releases event 2.1 that creates thing 2.1. Thing 2.1 starts event 3.1 which creates thing 3.1. Then, thing 3.1 generates a new version of the first event, i.e., event 1.2. In such a way, a new version of the first thing is created, which is called thing 1.2.

According to events and things, a managerial action can be represented by time domain features and content domain features, respectively [7], [50]. In this paper, we employ the time domain features since such features can be easily captured and quantized. In contrast, the content domain features involve words, sentences, expressions, characters, and figures, which are hard to be quantized by existing models [51].

Based on the analysis above, we denote a team manager by Ω and then represent it by managerial actions. This is different from the traditional approaches that represent Ω by managerial roles and managerial skills (Sections I and II). The rationale behind is that a managerial action can be defined as a real activity which a manager does in order to play a managerial role and have a certain managerial skill [35]. In such a case, a managerial action is the connection between a managerial role and a managerial skill. Consequently, the proposed representation method has higher description power and it can be an answer to the first research question mentioned in Section I. Table II illustrates an example of action features and their groups in the time domain. It can be clearly observed that a managerial action contains different types of features. Moreover, those features belong to several feature groups. In addition, different feature groups may have a different number of features. Based on these observations, in Section III-B, a managerial action is represented by a T-dimensional feature vector with H flexible feature groups.

TABLE II

EXAMPLE OF MANAGERIAL ACTION FEATURES AND THEIR GROUPS

Feature	Description	Feature Group
$f_1 \sim f_2$	Coding: Natural binary code	Group 1 (G_1): Type of a thing.
$f_3 \sim f_8$	Coding: Natural binary code	Group 2 (G_2): Number of a thing.
$f_9 \sim f_{14}$	Coding: Natural binary code	Group 3 (G_3): Version of a thing.
f_{15}	Create a new action	Group 4 (G_4): Planning metatype.
f_{16}	Edit an existing thing	
f_{17}	Analyse an existing thing	Group 5 (G_5): Recognition metatype.
f_{18}	View a map of all things	
f_{19}	Save creating or editing	Group 6 (G_6): Completion metatype.
f_{20}	Close creating or edit without saving	
f_{21}	Delete an existing thing	Group 7 (G_7): Function in the tools.
f_{22}	Print an existing thing	
f_{23}	Confirmation of deleting an exist thing	
f_{24}	Cancellation of deleting an exist thing	

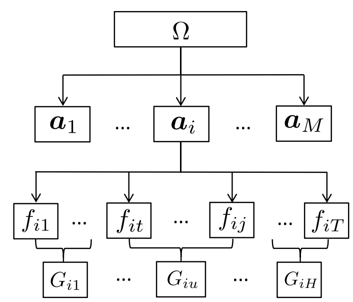

Fig. 2. Proposed model to represent a manager Ω.

B. Representation Model

As a manager is organized by several actions, we represent it by features of each action. Specifically, as shown in Fig. 2, a manager Ω is composed by M actions

$$\Omega = \{\boldsymbol{a}_1, \ldots, \boldsymbol{a}_M\}. \tag{1}$$

For a single action $\boldsymbol{a}_i$, it can be represented by a T-dimensional feature vector

$$\boldsymbol{a}_i = [f_{i1}, \ldots, f_{iT}]^{\mathsf{T}} \tag{2}$$

where f denotes a single feature value, $i = 1, 2, \ldots, M$. As discussed in Section III-A, those features can also be classified into H groups based on their characteristics, $H \leqslant T$. Moreover, the feature number in a group G_{iu} may be different from others, $u = 1, \ldots, H$. For example, in Fig. 2, G_{i1} and G_{iH} could have different feature numbers. For notational simplicity, we assume that the features of $\boldsymbol{a}_i$ are ordered according to the order of their groups. In such a case, $G_{im} = [f_{it}, \ldots, f_{ij}]$, $1 \leqslant t \leqslant j$, and $t \leqslant j \leqslant T$. Consequently, an action $\boldsymbol{a}_i$ can also be represented by feature groups

$$\boldsymbol{a}_i = \{G_{i1}, \ldots, G_{iH}\} \tag{3}$$

Considering all M actions of a manager Ω, it can be represented by all action features within H feature groups

$$\Omega = \{\boldsymbol{G}_1, \ldots, \boldsymbol{G}_u, \ldots, \boldsymbol{G}_H\}. \tag{4}$$

where $\boldsymbol{G}_u$ is a $M \times (j - t + 1)$ matrix in which all M action features within a feature group $[f_t, f_j]$ are preserved. The proposed representation method in (4) will be used for action sequence matching in Section IV.

It should be noted that the idea of representing a manager by feature vectors is not new [7]. Such an idea is also similar to one of the first research by Gilbreth in the field of scientific management at the beginning of 20th century [52]. They investigated human motions at work, which was the beginning of workforce automation in industries [53]. Moreover, in the literature, we can find other representation approaches used in production [54], healthcare services [55], process of physical

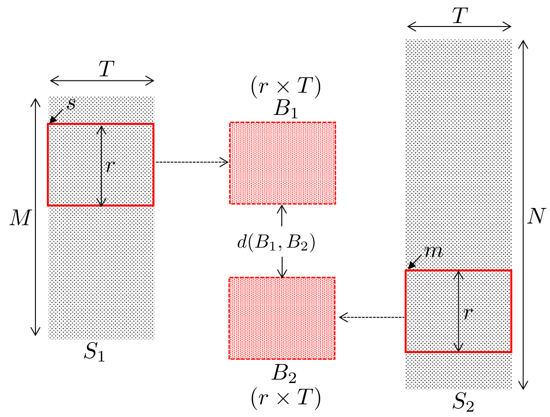

Fig. 3. Illustration of the general idea of partial matching. B_1 and B_2 are two $r \times T$ sized action blocks selected from the action sequences S_1 and S_2, respectively. $D(s, m, r)$ denotes the dissimilarity between B_1 and B_2.

workers [56], and, to some extent, in managerial work [57]. However, different from these approaches, our method is more flexible to be adapted in different scenarios. In addition, the proposed representation model in Fig. 2 is suitable to use in action sequence matching in Section IV.

IV. Team Manager Matching

Answering to the second research problem (Section I), we propose an efficient matching algorithm to find partially similar parts among action sequences from different team managers. Moreover, it is important to provide a reasonable similarity measure for tasks such as team manager comparison and retrieval, and so on. Therefore, a team manager similarity method is introduced in the second part of this section.

A. Partial Matching

In order to find a partial match between two given team managers Ω_1 and Ω_2, their corresponding action sequences S_1 and S_2 are compared. As introduced in Section III-B, each action $\boldsymbol{a}$ is described by a T-dimensional feature vector. Therefore, the action sequences S_1 and S_2 can be represented by feature matrices with size $M \times T$ and $N \times T$, respectively. M and N are the number of actions. For notational simplicity, we assume that $M \leqslant N$.

The aim of team manager matching is to identify parts of the two action sequences that are similar to each other. In terms of comparing the two descriptor matrices, as shown in Fig. 3, it equals to find $r \times T$ sized feature blocks B_1 and B_2, starting at the action $\boldsymbol{a}_{1s}$ in S_1 and $\boldsymbol{a}_{2m}$ in S_2 which yield a small dissimilarity value $d(B_1, B_2)$. r is the number of actions in the matching blocks B_1 and B_2. s and m denote the index of start actions in S_1 and S_2, respectively. As illustrated in (4), each team manager Ω can be represented by H feature groups. Since B_1 and B_2 have the same dimensional features and feature groups as Ω, they can also be represented as

$$\begin{aligned} B_1 &= \left\{\boldsymbol{G}'_{11}, \ldots, \boldsymbol{G}'_{1u}, \ldots, \boldsymbol{G}'_{1H}\right\} \\ B_2 &= \left\{\boldsymbol{G}'_{21}, \ldots, \boldsymbol{G}'_{2u}, \ldots, \boldsymbol{G}'_{2H}\right\} \end{aligned} \tag{5}$$

where $\boldsymbol{G}'_{1u}$ and $\boldsymbol{G}'_{2u}$ are the $r \times (j - t + 1)$ feature group matrices, $u = 1, \ldots, H$. This is because a feature group $\boldsymbol{G}'$ contains r number of actions. Moreover, as shown in (4) and Fig. 2, the feature number in a feature group is indicated by $(j - t + 1)$.

Based on (5), $d(B_1, B_2)$ is calculated by the integrated Bhattacharyya distance [58] from H feature groups

$$d(B_1, B_2) = \frac{1}{H} \sum_{u=1}^{H} \lambda_u D_B\left(\boldsymbol{G}'_{1u}, \boldsymbol{G}'_{2u}\right) \tag{6}$$

where λ is the weight for fusing H feature groups and $D_B(\boldsymbol{G}'_{1u}, \boldsymbol{G}'_{2u})$ denotes the Bhattacharyya distance between two feature groups. In practice, λ can be searched using the heuristic method of gradient hill climbing integrated with simulated annealing [59]. Otherwise, it can be set to one for all feature groups. Specifically, the gradient hill climbing [60] method starts with randomly selected parameters. Then, it changes single parameters iteratively to find a better set of parameters. A fitness function then evaluates whether the new set of parameters performs better or worse. The simulated annealing strategy [61] impacts the degree of the changes. In later iterations, the changes to the parameters are becoming smaller. Consequently, with a small part of testing data in the preliminary experiments, $\lambda_1, \ldots, \lambda_H$ can be properly assigned.

Furthermore, the Bhattacharyya distance $D_B(\boldsymbol{G}'_{1u}, \boldsymbol{G}'_{2u})$ is calculated as

$$\begin{aligned} &D_B\left(\boldsymbol{G}'_{1u}, \boldsymbol{G}'_{2u}\right) \\ &\quad = \frac{1}{4} \ln\left(\frac{1}{4}\left(\frac{\sigma_{1u}^2}{\sigma_{2u}^2} + \frac{\sigma_{2u}^2}{\sigma_{1u}^2} + 2\right)\right) + \frac{1}{4}\left(\frac{(\mu_{1u} - \mu_{2u})^2}{\sigma_{1u}^2 + \sigma_{2u}^2}\right) \end{aligned} \tag{7}$$

where σ and μ are the variance and mean of a feature distribution, respectively. With (7), the Bhattacharyya distance among all feature groups can be calculated and then the global dissimilarity $d(B_1, B_2)$ between two feature blocks B_1 and B_2 is generated using (6).

As introduced above, $d(B_1, B_2)$ is built on the combination $\{s, m, r\}$. s and m indicate the start action index for building action blocks B_1 and B_2, respectively (see Fig. 3). Therefore, to find similar blocks among S_1 and S_2 all different matching possibilities and chain lengths r have to be considered and the brute-force method [62] becomes inefficient for larger number of actions. Therefore, different authors, e.g., [63], proposed approximations where, for example, only every nth action is considered as the starting action.

Inspired by [7] and [64], we propose an algorithmic optimization to overcome the limitations of the brute-force approach [63]. The proposed method is based on a modified Summed-Area-Table (SAT) approach [65] to calculate all the dissimilarity values $d(B_1, B_2)$ among different combinations of $\{s, m, r\}$. The SAT concept was originally proposed for texture mapping [66] and then brought back to the community of computer vision by Viola and Jones [67] as integral image. The integral image concept allows to calculate rectangle image features like the sum of all pixel values for any scale and any location in constant time [64]. However, different from the method [64] in which N integral images are generated for triples $\{s, m, r\}$ searching, the proposed method only uses M integral images to speed up the matching process.

Particularly, in order to calculate the dissimilarity value $d(B_1, B_2)$ for all possible configuration triplets $\{s, m, r\}$ in the most efficient way, M integral images $Int^1, \ldots, Int^r, \ldots, Int^M$ are built based on (6) for the block length r from 1 to M. In such a case, each integral image Int^r is the $(M-r) \times (N-r)$ matrix. The main reason is that we need to consider all possible matches from action blocks in S_1 and action blocks in S_2. Based on these M integral images the dissimilarity values $d(B_1, B_2)$ can be calculated for every block of any length starting at any action in constant time.

Finally, all matching triples $\{s, m, r\}$ which provide a dissimilarity value $d(B_1, B_2)$ below a fixed threshold are returned as the final matched parts among two action sequences S_1 and S_2. As discussed in [64], the detected matches may overlap. Therefore, the final result is obtained by merging the different returned matches.

B. Team Manager Similarity

To calculate the global similarity between two team managers Ω_1 and Ω_2, a combination of descriptor difference [68] and the bending energy of an estimated transformation [69] is commonly used. However, these methods normally only focus on the coarse-grained differences among action sequences S_1 and S_2 and the property of fine-grained similar and dissimilar blocks are not fully used. Moreover, in Section IV-A, we already collect the partial dissimilarities with all possible block lengths. With this in mind, we adapt a measure described by Flak *et al.* [7], Donoser *et al.* [64], and Bronstein *et al* [70] to calculate the global similarity between team managers.

Specifically, we use a Pareto-framework for quantitative interpretation of partial similarity. In order to do so, two quantities are defined: partiality $\xi(B_1, B_2)$, which describes the block lengths (the higher the value, the smaller the part) and dissimilarity $d(B_1, B_2)$, which measures the dissimilarity between the blocks, where B_1 and B_2 are two action sequence blocks. In this paper, partiality is calculated by $\xi(B_1, B_2) = 1/r$. A pair $\Phi(B_1, B_2) = (\xi(B_1, B_2), d(B_1, B_2))$ of partiality and dissimilarity values, fulfilling the criterion of lowest dissimilarity for the given partiality, defines a Pareto optimum [64]. All Pareto optimums can be visualized as a curve, referred to as the set-valued Pareto frontier. As described in Section IV-A, the proposed partial matching algorithm automatically evaluates all possible matches for all possible block lengths, we can easily collect all Pareto optimums $\Phi(B_1, B_2)$ by focusing on the minimum dissimilarity values in M integral images.

Finally, to get the global similarity $D_S(\Omega_1, \Omega_2)$ between mangers Ω_1 and Ω_2, as shown in Fig. 4, the so-called Salukwadze distance [7], [70] is employed based on the collected Pareto frontier as

$$D_S(\Omega_1, \Omega_2) = \inf_{B_1, B_2} |\Phi(B_1, B_2)|_1 \tag{8}$$

where $|\cdots|_1$ is the L1-norm of the vector which contains all pairs of partiality and dissimilarity. Consequently, $D_S(\Omega_1, \Omega_2)$ measures the minimum distance from the origin $(0, 0)$ to the point on the Pareto optimum. The Salukwadze distance is then returned as the similarity value of team managers Ω_1 and Ω_2.

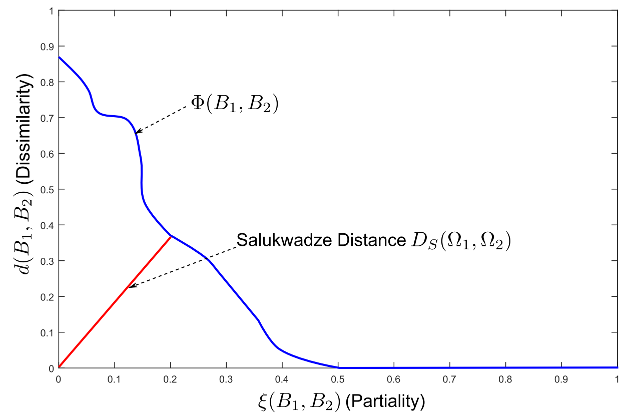

Fig. 4. Proposed approach for calculating similarity between team managers using the Salukwadze distance.

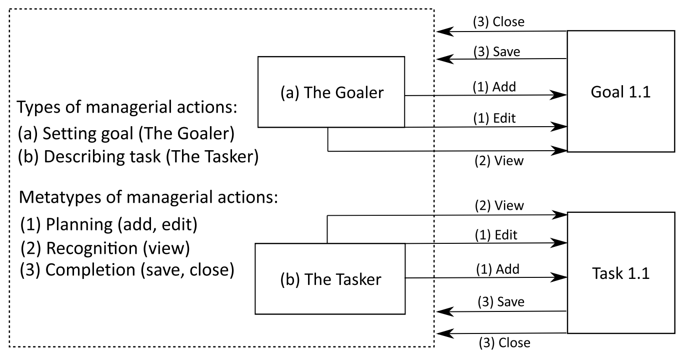

Fig. 5. Fundamental structure of tools.

V. Research Method

For evaluating the proposed team manager representation and matching approaches, we design an online experimental platform, *transistorshead.com*, to collect and represent managerial actions from different managers. This platform was designed based on the main idea in Section III-A and the principles are as follows.

1) Every online management tool tracks and records managerial actions according to the idea of Unit of Behaviors [71].
2) Using a management tool by a team manager is equal to an event occurring in an organizational environment which results in a thing [72].
3) Each online management tool is useful for describing managerial actions.

Following these principles, more concrete idea is illustrated in Fig. 5. Particularly, tools in the experiment are constructed by two components: Goaler for setting goals and Tasker for describing tasks. If a manager created a new goal, e.g., Goal 1.1 (*add*), the parameters of this goal should be setted first, then save or withdraw the settings (*save*). The goal can also be edited (*edit*). The manager can analyze (*view*) the goal and then close it (*close*). Functions of Tasker are similar to Goaler. These operations and functions are assigned to record features of managerial actions as described in Table II.

Fig. 6 shows the real interface of this platform based on the idea in Fig. 5. A dashboard of the system is divided into several parts. At the top, there is a panel with "System functions."

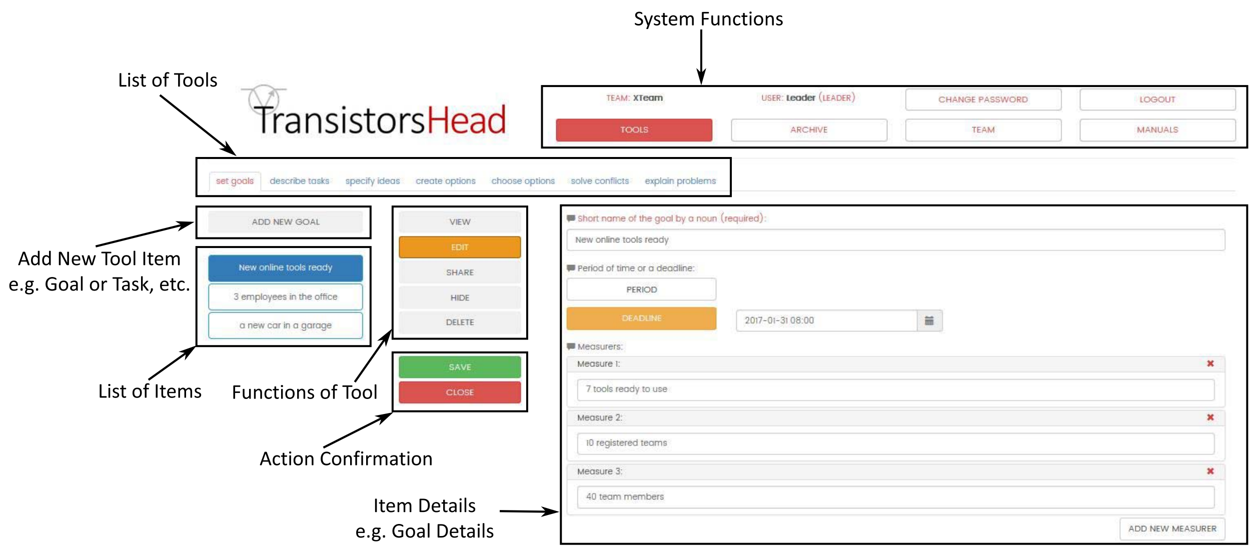

Fig. 6. Main interface of Transistorshead platform.

Managers can choose working with tools (*TOOLS* default), add members of their teams (*TEAM*), hide some created items into archive (*ARCHIVE*) and read instructions how to use the tools (*MANUALS*). There are also functions like login, logout, and changing password.

The main menu "List of tools" consists of seven different tools for team management, e.g., set goals, describe tasks, specify ideas, and create options. Here, only two tools are used according to the idea in Fig. 5: Set goals and describe tasks for Goaler and Tasker, respectively. The rest tools will be employed and explored for team matching in our future work. With these two tools, we can easily record each managerial action and describe it with a 24-dimensional feature vector. Those features are grouped into seven feature groups (see Table II). Below the main menu, there are three vertical parts:

1) In the left parts, there is the "Add New Tool Item" function which means that in every tool a manager can create a new item, e.g., a new goal in the Goaler. Below this button there is a "List of Items" created in the chosen tool, e.g., lists of goals in the Goaler (the chosen item is in blue color).
2) In the middle vertical part is the universal area "Functions of Tool" (the same buttons for every tool), such as *view* (viewing the chosen item), *edit* (making changes in the chosen item), *share* (sharing the chosen item to team members), *hide* (hiding the chosen item in the archive), and *delete* (deleting the chosen item from the list if items but not from the database). Below this area, there are also universal buttons of "Action Confirmation" a manager can *save* the item in the tool or *close* the tool without saving. *save* confirmation uploads the database with new data about the item, e.g., new goal parameters in the Goaler, and it creates the representation of a particular managerial action, e.g., editing a goal in the Goaler.
3) In the right vertical part, there is an "Item Details" area for forms, buttons, text areas, or combo lists which a manager uses to establish the content of the tool item, e.g., a goal's name, deadline, and measures. This vertical part contains different elements for every tool depending of the designed item parameters. The only common and required element is a name of the item.

With this platform, we have collected and built our data set: PG-Manager. Particularly, in order to collect the managerial actions, 150 volunteers had been involved in our experiment over 15 months. Most of them were daily students of Business Management at the University of Economics in Katowice, Poland. They use this platform to manage their team works. Some volunteers were the platform users from different domains and countries, like research group leaders, small company managers, and so on. Each group consists of a team manager and multiple members. Consequently, PG-Manager contains 56 managers and each manager contains 200–400 managerial actions which are represented by the 24-dimensional feature vectors. For each team manager, based on the theory in [42], a label is assigned by considering the following factors: 1) experience; 2) knowledge of management techniques; 3) academic subject; 4) full- or part-time; 5) age; and 6) team achievement. Manager labels can be used as a ground-truth for evaluating our experimental results. In total, there are seven labels in this data set.

VI. Results of the Experiment

In this section, we evaluate the performance of the proposed manager representation and matching methods in a structured way. Based on the proposed experimental platform in Section V, each managerial action is represented by different action features within different groups. Built on the represented manager, we apply the manager matching experiment and compare the matching results to the ground truths and human perception. Finally, the computational complexity of the proposed manager representation and matching methods are analyzed and discussed.

The experiments in this paper are performed on two environments: the experimental platform (transistorshead.com) is applied on the server of *home.pl*, a commercial hosting provider. With this platform, we can efficiently collect and represent managerial actions in real time. The managerial action sequence matching experiments are accomplished on a laptop with Inter Core i7 2.2-GHz CPU, 8.00-GB memory, and 64-bit Windows 8.1 OS. The representation and matching methods in our experiments are implemented in PHP and MATLAB, respectively.

A. Evaluating Team Manager Representation

To access the usability of the proposed manager representation method, we apply a classification experiment on the PG-Manager data set. Because the action features are high-dimensional in this data set, we select a support vector machine (SVM) as a classifier. Compared to the SVM, similarity-based classifiers like k-Nearest Neighbor and probability-based classification methods like Naive Bayes do not work well for high-dimensional features. The main reason is that similarity-based classifiers fail to appropriately measure the similarity values for high-dimensional feature spaces due to many irrelevant dimensions unnecessarily taken into consideration. Probability-based classifiers need a large number of manager examples to appropriately estimate probabilistic distributions in high-dimensional feature spaces [73]. However, due to the limited number of volunteers in our experiment, it is difficult to collect a large and statistically relevant set of managers for training.

For these reasons, we have selected an SVM which extracts a decision boundary between different classes of managers based on the margin maximization principle. Due to this principle, the generalization error of the SVM is theoretically independent of the number of feature dimensions [74]. Furthermore, a complex (nonlinear) decision boundary can be extracted using a nonlinear SVM. In this paper, we applied a multiclass SVM (mSVM) using its one-against-one (1vs1) version which works with a voting strategy. It uses a two-class SVM for each pair from a set of all considered classes. Thus, if there are K classes in total, $K(K-1)/2$ two-class classifiers have to be used. First, a sample pattern (query pattern) is classified using all these two-class SVMs. The final classification result is determined by counting to which class the sample pattern has been assigned most frequently.

In practice, since each manager is composed by different number of actions, we calculate the mean value and the standard deviation of each feature among all actions. Then, a manager is represented by a $(2 \times T)$-dimensional feature vector. Due to the fact that there are only a limited number of managers and features, we select the radial basis function (RBF) as the kernel of SVM. In general, the RBF kernel is a reasonable first choice. This kernel nonlinearly maps samples into a higher dimensional space so that, unlike the linear kernel, it can handle the case when the relation between class labels and attributes is nonlinear [75]. Furthermore, the linear kernel is a special case of RBF [76] since the linear kernel with a penalty parameter $\widetilde{C}$ has the same performance as the RBF kernel with some parameters (C, γ). In this paper, we assign the SVM parameters C and γ by a grid-search method [75] so that the classifier can accurately predict unknown manager classes.

TABLE III
SVM-BASED MANAGER CLASSIFICATION RESULTS WITH THE PROPOSED MANAGER REPRESENTATION METHOD

Round	Classification Rate
1	75%
2	100%
3	100%
4	87.5%
5	75%
Total	**87.5%**

For the experiment, we randomly select four managers from each class for supervised training. For the testing, the remaining managers from each class are used. In order to increase statistical relevance, we repeated the selection process five times which led to five different training data sets. Experiments are performed for all these data sets and mean classification rates are considered for evaluation. Table III illustrates the classification rate in each round. It can be clearly observed that the proposed manager representation method achieves a promising performance: 87.5% in total. Moreover, we find that the misclassified managers occurred mostly due to the outliers within action sequences. This phenomenon suggests that in the future an action filtering process is required to remove noisy actions from action sequences.

However, it should be noted that this experiment is only designed to evaluate the usability of the proposed manager representation approach. This classification method is not suitable for the applications in practice. The main reason is that the $(2 \times T)$-dimensional feature vector contains only hand-crafted features that are designed based on prior knowledge about data. Moreover, these features are not statistically optimal and lack the detained information, e.g., variance, frequency, and shape of the sequence. Finally, considering the growing number of actions from different managers, the traditional SVM-based approach cannot efficiently handle such a big data. Therefore, in the future, some feature learning approaches [77] will be employed to extract features that are not only statistically validated but also can preserve the detailed information.

B. Evaluating Team Manager Matching

To evaluate the proposed manager matching algorithm, we perform the managerial action sequence matching experiments on the PG-Manager data set. Specifically, our evaluation is built on a retrieval framework where managers in the data set are ranked based on their similarity to a query. Based on the ranked results and similarity values, we can distinguish different managers and also group them into different classes. Table IV illustrates the similarities between eight most similar managers in which the similarity values are above the threshold[1] $\sigma = 0.97$. In short, these eight managers have the highest similarity values among all 56 managers.

When we called the labels of team managers as the ground truth, mentioned in Section V, these eight managers were

[1]An empirical threshold based on the distribution of all similarity values during our retrieval experiment.

TABLE IV
SIMILARITIES BETWEEN SIMILAR MANAGERS

	Manager1	Manager2	Manager3	Manager4	Manager5	Manager6	Manager7	Manager8
Manager1	1	0.9919	0.9932	0.9797	0.9878	0.9702	0.9925	0.9706
Manager2	0.9919	1	0.9869	0.9868	0.9946	0.9769	0.9940	0.9704
Manager3	0.9932	0.9869	1	0.9702	0.9871	0.9708	0.9866	0.9766
Manager4	0.9797	0.9868	0.9702	1	0.9821	0.9749	0.9896	0.9705
Manager5	0.9878	0.9946	0.9871	0.9821	1	0.9702	0.9906	0.9721
Manager6	0.9702	0.9769	0.9708	0.9749	0.9702	1	0.9701	0.9724
Manager7	0.9925	0.9940	0.9866	0.9896	0.9906	0.9701	1	0.9703
Manager8	0.9706	0.9704	0.9766	0.9705	0.9721	0.9724	0.9703	1

TABLE V
FEATURE STATISTICS AMONG THE SELECTED MANAGERS

Managers	1	2	3	4	5	6	7	8
Total Time	104107	61017	49000	64920	50474	65796	65431	49110
Duration of Teamwork	314	252	246	382	380	517	530	197
Number of Logins (See Table 6)	8	7	4	5	6	13	11	2
Number of Managerial Actions	307	215	172	145	518	373	443	89
Number of Managerial Actions (per Minute)	0.98	0.85	0.70	0.38	1.36	0.72	0.84	0.45
Number of Created Objects (goals and tasks)	25	18	24	10	33	10	32	8
Number of Created Objects (goals and tasks) per Minute	0.08	0.07	0.10	0.03	0.09	0.02	0.06	0.04
Number of Goals	8	6	8	5	3	4	8	7
Number of Tasks	17	12	16	5	30	6	24	1
Number of Goals Edition Attepmts	64	20	14	23	42	161	61	9
Number of Tasks Edition Attempts	37	31	25	17	113	23	110	0
Number of Saved Goals Editions	0	13	9	11	25	99	17	5
Number of Saved Tasks Editions	0	22	15	5	78	5	44	0
Number of Saved Editions by Object (goal)	0.00	2.17	1.13	2.20	8.33	24.75	2.13	0.71
Number of Saved Editions by Object (task)	0.00	1.83	0.94	1.00	2.60	0.83	1.83	0.00

very similar to each other. According to these labels, all of team managers had such features: 1) they were beginners; 2) they had the same knowledge of management techniques basing on; 3) the same academic subjects; 4) they did not work full time at any position; and 5) they were in the same age of 23–24; (5) they worked on the same task and each team had the similar achievement on this task (planned project). In such a case, they belonged to the same class of managers.

In addition, we apply a deeper analysis of these managers. Tables V and VI show the detailed statistics of eight managers from different perspectives, including time, team works, logins, actions, and so on. From human perception point of view, these managers arranged their projects in completely different ways. First of all, "Total Time" from first login to final logout shows that managers did their work in shorter or longer periods of time. For instance, manager 1 worked twice as much as manager 3. Moreover, the parameter "Duration of Teamwork" describes what was real time of using the Goaler and the Tasker by managers. They also worked differently: manager 7 spent much more time on working with tools than managers 4 and 8. Finally, the human perception of their differences is even amplified by the "Numbers of Logins," e.g., manager 6 logged into the platform 13 times and a manager 8 only has two records. The other differences of ground parameters, such as "Number of Managerial Actions," "Number of Created Objects," and login details (Table VI) also confirm this perception.

TABLE VI
DURATION OF STAY IN EACH LOGINS (MINUTES, "-": NONE)

	Managers							
Logins	1	2	3	4	5	6	7	8
1	1	64	35	83	57	1	72	156
2	1	1	149	101	2	76	54	41
3	9	10	1	13	106	1	2	-
4	60	3	61	181	99	44	75	-
5	148	6	-	4	46	93	109	-
6	33	140	-	-	70	3	199	-
7	3	28	-	-	-	81	1	-
8	59	-	-	-	-	13	3	-
9	-	-	-	-	-	26	1	-
10	-	-	-	-	-	38	10	-
11	-	-	-	-	-	19	4	-
12	-	-	-	-	-	114	-	-
13	-	-	-	-	-	8	-	-

However, calling the ground truth, these eight managers are very similar to each other: they were beginners, they had the same knowledge of management techniques basing on the same academic subjects, they did not work full time at any position, they were in the same age, they worked on the same task, and each team had the similar achievement on this task. In such a case, they belong to the same class of managers. Considering the ground truth, we can clearly observe that the proposed method can group the managers correctly. Moreover, compared to the ground truth and human perception, the proposed method not only returns the information that managers are similar (or dissimilar) from each other but also provides more accurate similarity scores and their similar action sequences. In such a case, scientists and practitioners can apply a deeper exploration in management science.

C. Computational Complexity

Here, the computational complexity of the proposed manager representation and matching approaches in Sections III-B and IV is analyzed.

1) For manager representation, the proposed method in Section III-B generally includes two parts: managerial actions and action features. For managerial actions, the time complexity is $O(M)$ since a manager Ω is composed by M actions. For a single action $\boldsymbol{a}$, since it can be represented by a T-dimensional feature vector, the time complexity is $O(T)$. Therefore, the total complexity is $O(MT)$. Recalling that in practice there are many more managerial actions than the number features ($M \gg T$), the total complexity for manager representation is bounded by $O(M)$.
2) For manager matching, an exhaustive search over all possible matches for all possible block sizes has a complexity of $O(2^{N_1+N_2})$, where N_1 and N_2 are the number of actions within the two input managers. Our proposed approach based on integral image analysis enables matching in $O(N_1 N_2)$ time. We implemented our method in MATLAB, which enables manager matching on a laptop within seconds.

VII. Discussion

Nowadays the job of team managers inevitably becomes more and more complex, which means that they need to be able to organize not only their own time and processes but also those of the team members. In this meaning, a team is defined as a social system of two or more units that are embedded in an organization, which members perceive themselves and each other as members and collaborate on a common task [2]. To be effective, team managers need to become more fluent with the consistent application of systems and business processes into team work.

A. Potential Applications

The proposed team manager representation and matching methods create the first step to design several applications for the business practice. Based on our experience in working with managers and companies, we see at least three such applications:

First, the management similarity is usual practical problem in big companies where the managers, i.e., team leaders or project managers, should work with external or internal clients delivering them specified results [78]. Especially, big companies put a lot of effort to standardize employees' work and their results. That is why presented team manager representation and matching methods let establish a level of similarity between managers on similar positions in the company [79]. This representation and matching method could be implemented in common online project management tools well known in the business practice [80], [81]. This makes the work of project managers more efficient and coherent.

Second, the team manager matching method can be employed in the applications concerning the recruitment process to any organization. In some cases of managerial position there is organized assessment center for candidates. It is usually a place with a conference room where a few candidates have to solve a problem together during 2–3 days. They are observed by human resource (HR) specialist, psychologists, experienced managers, and so on. However, the results of such observations are quite qualitative and vague. If the candidate could work not only with sheets of paper but also some online management tools (such as described above and shown in Fig. 6), there would be an opportunity to assess how much their style of management fit to the requirements on the vacated positions [82]. This assessment would much more precise and detailed than done by a traditional assessment method.

Third, the team manager representation method lets create a model of managerial actions in any situation and of any kind. In this paper, we tested the method only with two types of actions setting goals and describing tasks. However, the same representation method can be used for any other actions, such as generating ideas, creating options, checking motivation, and so on. Recording managerial actions based on this representation method is essential to get data useful in concluding on the dominating habits of a certain managers and his behavior [83]. This lets build a model of his personal managerial style and to apply this model when we want to pretend such a manager in a real life. This leads inevitably to replacement of human managers with robots in certain types of managerial work, such as setting goals and planning tasks, preparing meetings, checking motivation of a team, and so on. which was predicted by Drucker [84]. After the first age of robotics in mechanical processes and manufacturing, rapid development of computer science and Internet gives opportunities to replace team managers with robots [85].

However, there are some other challenges in such research which have to be overcome in the future. First, we need to use more online management tools for experiments. Currently there are only two online management tools (Section V) for verifying the proposed team representation and matching methods. The team managers had to plan projects with Goaler and Tasker. Concerning the pattern of managerial actions in Fig. 1, there were only two types of managerial actions which were focused on goals and tasks. There comes a research question what would be the results of team manager matching when we could use a data set which would come from seven existing or even a bigger number of online management tools. This is the future area of research.

Second, since the team managers used online management tools when they were performing their main task (planning project), there was an influence of online management tools on the features of managerial actions [86]. Taking this knowledge into consideration, there comes a research question about a level of this influence on the managerial actions which really appear. In other words, what is a bias error of such research tools as online management tools. Despite the previous research experience, it is still worth evaluating.

Third, in the experiment data set, only the managerial actions done by team managers were taken into consideration. However, the team managers never act alone. As described and defined in Section I, they used to lead team members. Hence, there is an emerging research question about the member actions which are taken as a response to managerial actions, e.g., what they are, when they appear, what are their features in a content domain, and so on. Answers to these research questions are going to be given in the next experiments with online management tools which could be shared with team members. Section VIII indicates some future extensions of our work to deal with these challenges.

B. Diversity

In this section, we extend the proposed methodology to other domains to address its diversity. Specifically, the proposed algorithms could be employed in business, science, and arts.

First, in HR management, there is a problem of people performance measurement. It is claimed that a subject of human work has always come to a simple question: what makes a man at work? [87], [88]. It gives great opportunities for managers to compare the performance of employees using our proposed manager representation method. Specifically, it can be used in: 1) systems of employee measurement; 2) motivating systems; 3) recruitment and development systems; and 4) time and production management systems. If the similarities between people working on the similar positions are able to describe, it would be possible to design more efficient methods of paying for their job, motivate employees with similar needs characteristic by nonfinancial factors, and conduct more adequate recruitments for similar positions. The advantage of this methodology would also increase time accuracy in production lines and let compare physical workers to one another.

Second, in science, there is a strong need of conducting more efficient scientific research with less funds achieving better and more accurate results. The question is what is the most efficient method of scientific research in a certain discipline which results in most cited and relevant publications? If two or more scientists in the same discipline could be tracked what they really do, there could be some similarities in their work discovered by this methodology. Of course, another question is what kind of measure tools could be used for tracking scientists work, especially abstract work of designing, reasoning, or drawing conclusions. The tools implemented in the TransistorsHead are not enough, because they use only the web page technology. There is a need of designing other tools which could measure changing location, acceleration of a body, barometric pressure for blood pressure, ambient body temperature, heart rate, or skin conductance. However, the methodology of representing work or other issues of activities is the same as it was describe in this paper.

Third, in arts, especially in movie and TV production, there is a lack of concrete and stable knowledge how to design and produce movies and TV programs. Tracking directors or producers work could be useful to formulate the pest practices in fields, which are still covered under the misty art performance. As we introduce in Section III-B, the idea of managerial action research in different domains was used in the past. For instance, time motion study [10], production [54], healthcare services [55], process of physical workers [56], and at least, to some extent, in managerial work [57]. The aforementioned applications are also similar to one of the first research in the field of scientific management, made by Gilbreth at the beginning of 20th century [52]. They investigated human motions at work, which was the beginning of workforce automation in many industries [53]. However, recording team managerial actions in such an extended scale and at the level of accuracy proposed in Sections III and IV has yet not been done before.

VIII. CONCLUSION

In this paper, we propose a novel team manager representation model and a matching algorithm based on managerial actions and their features as solutions to two methodological problems mentioned in Section I:

As a solution of the first problem, which is searching for a method of modeling a team manager in order to fully represent the characteristics of managerial actions, we first represent a team manager by action sequences collected by online management tools within the research platform *transistorshead.com*. After that, each managerial action is described by multiple time domain features within certain feature groups. In such a case, the proposed representation method is flexible and general enough to cover most types of team managers.

Trying to solve the second research problem, which is a lack of an algorithmic method of distinguishing team managers based on the action sequences of managers, we first apply a partial matching method to search the matched blocks within action sequences. Then, the global similarities between managers are calculated based on their matched sequence blocks. As presented in Section VI, the proposed team manager representation and matching methods are much more efficient compared to human perception based on statistics of managerial actions. Taking into consideration the groundtruth in evaluating our experimental results, which is based on labeling managers, we can conclude that both methodological problems in Section I are solved in a high level of accuracy than it has occurred traditionally.

In the future, we will extend our team manager representation method by adding more types of managerial action and action features. In addition, we will try to implement the proposed algorithms for team manager labeling based on the exiting deep learning approaches. In order to obtain huge number of experimental data for training deep learning models, we will take advantage of agent-based modeling [89] or artificial societies [90] for management actions modeling. Finally, we will employ and explore more tools for team members analysis and comparison.

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