

INTERDISCIPLINARY DESCRIPTION OF COMPLEX SYSTEMS

Scientific Journal

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INDECS, volume 18, issue 4, pages 408-524, year 2020

Published 30th October 2020 in Zagreb, Croatia

Released online 30th October 2020

Office

Croatian Interdisciplinary Society

c/o Faculty of Mechanical Engineering & Naval Architecture

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Published by *Croatian Interdisciplinary Society* (<http://www.idd.hr>) quarterly as printed (ISSN 1334-4684) and online (ISSN 1334-4676) edition. Printed by *Redak d.o.o.* (HR) in 50 pieces. Online edition, <http://indec.s.eu>, contains freely available full texts of published articles.

Journal INDECS is financially supported by Croatian Ministry of Science and Education.

Content of the journal INDECS is included in the DOAJ, EBSCO, EconLit, ERIH PLUS, Ulrich's and Web of Science Core Collection.

INDECS publishes original, peer-reviewed, scientific contributions prepared as reviews, regular articles and conference papers, brief and preliminary reports and comments to published articles. Manuscripts are automatically processed with the system Comet, see details here: <http://journal.sdewes.org/indec.s>.

The accessibility of all URLs in the texts was checked one week before the publishing date.

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EDITORIAL

Dear readers,

you read the last issue of the 18th volume of the journal INDECS, that contains nine high-quality articles about diverse topics. I am glad how the articles combine on the one hand applicability and contemporariness of their content, and on the other hand the thoroughness of the methodology utilised.

Having in mind the current pandemic situation in the world, the articles dealing with the topic of COVID 19 form a separate section. It is not a custom to introduce changes and some modifications in the journal in the last issue of a volume.

However, it is considered that such an approach goes along with the efforts of the journal INDECS to contribute within its capabilities to reaching the global, optimal response to the COVID 19 pandemic. We will continue to do so.

Zagreb, 29th October 2020

Josip Stepanić

INDECS AWARD

Dear authors of articles published in Vol. 17 of the journal INDECS,

the contest for the INDECS award, INDECOSA 2020, choosing of the best article published in INDECS during 2020, i.e. in Vol. 18, is opened.

The voters are you, the authors of articles published in INDECS Vol. 17, i.e. in 2019, and the members of the INDECS' Editorial Board. Each and every voter contributes with one vote.

Propositions for the INDECOSA are available from the web site of INDECOSA, <http://indec.s.eu/index.php?s=indec.s>.

I would like to ask you to give your vote to the article which you consider to be the best among the articles published in the year 2020.

The votes will be collected till 28th February 2021 and the results will be presented in INDECS 19(1).

Cordially,

Zagreb, 27th October 2020

Josip Stepanić

CROATIAN CRISIS MANAGEMENT SYSTEM'S RESPONSE TO COVID-19 PANDEMIC THROUGH THE LENS OF A SYSTEMIC RESILIENCE MODEL

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DOI: 10.7906/indecs.18.4.1

Regular article

Received: 29 July 2020.

Accepted: 9 September 2020.

ABSTRACT

We analyse the Croatian crisis management system's response to COVID-19 pandemic in terms of Fath, Dean, and Katzmaier's [1] model of resilience in social systems. We find that the Croatian crisis management system has successfully completed one cycle of the model. However, if the system is to achieve resilience, it also needs to replace the regime from before the crisis with a new regime that will simultaneously enable a life of relative normalcy and contain an excessive spread of the virus. Strengthening social cohesion and more bottom-up, emergent leadership might facilitate the search for a new regime. Small, local outbreaks represent small-scale disturbances that provide opportunities for the development of cohesion and bottom-up leadership from local, county, municipal and city-levels to the national level. The model used in this article better conveys the underlying complexity of crisis management systems than "the hammer and the dance" model, whereas the latter is better suited for public communication. Future work should extend this case study in terms of modelling approaches, the sample of countries, and the time covered. It can also be extended to lower, sub-national, as well as higher, supra-national levels, such as the EU.

KEY WORDS

COVID-19 pandemic, crisis management, societal resilience, systemic resilience, the hammer and the dance

CLASSIFICATION

JEL: H12

PACS: 89.60.Gg

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INTRODUCTION

Resilience, a concept understood as “the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must” [2; p.1034], has its roots in ecology [3] and materials science [4]. However, the concept has recently been extended to diverse scientific disciplines, such as behavioural and brain sciences [5], social psychology [6], social work [7], economics [8], sociology [9, 10], political science [11], crisis management and security issues [12-14], among others.

In this article we use a model of resilience in social systems, proposed by Fath, Dean and Katzmaier [1], to analyse the Croatian crisis management system's (CCMS's) response to COVID-19 pandemic in the first half of 2020. The purpose of the analysis is to look at the CCMS's response through the lens of the model, and use the insights obtained to better understand the system's resilience and see whether it can be further improved.

By the CCMS in this article we mean, in the first place, hierarchical network of civil protection headquarters (CPHs), with the national CPH at the top level, county CPHs at the intermediate level, and municipal and city CPHs at the local level. The Croatian Government tasked the national CPH with coordinating activities related to responding to the COVID-19 pandemic in Croatia [15], and the national CPH authorised the lower-level CPHs to coordinate activities within their local areas [16]. As the CCMS cannot be separated from the rest of society, the discussion will also occasionally touch on the relations between the CCMS and the wider political, economic, and civil society spheres.

This research effort is a case study which can be extended toward a more comprehensive comparative research framework, as outlined in the concluding section. The main reason why we chose Fath, Dean and Katzmaier's model as a tool for analysis is the balance between simplicity and complexity that seems to be just right for an initial case study. In particular, we shall show later that this model is more complex than another often cited model addressing issues related to the COVID-19 pandemic – “the hammer and the dance model”. Yet, the model we use is simpler than other systemic resilience approaches, such as ecological information-based networks and models using statistical evidence of resilience [17]. As noted in the concluding section, we may try some of the more complex models in future research.

The article is structured as follows. In the next section, we briefly describe Fath, Dean and Katzmaier's model of systemic resilience. Then we analyse CCMS's response to COVID-19 pandemic in terms of the model. We particularly discuss implications of the analysis for resilience of the CCMS, social cohesion, leadership, candidates for the measure of strain on resources in the model, the role of small-scale disturbances, and the comparison of Fath, Dean and Katzmaier's model with “the hammer and the dance” model. We conclude by recapitulating the main findings, spelling out their policy implications, and outlining possible extensions of our analysis.

THE MODEL OF RESILIENCE IN SOCIAL SYSTEMS

The model of resilience in social systems, described by Fath, Dean and Katzmaier [1], is an extension of previous models developed in the field of ecology by Holling [18], and Burkhard, Fath and Müller [19]. The model is based upon the “panarchy approach” [20-22], which conceptualises the resilience of a system as a two-dimensional adaptive cycle. Degree of system's institutionalisation, which reflects flexibility or rigidity of the system, is represented by the abscissa, while the system's resources, which reflect the systems adaptive potential for change, are represented by the ordinate [17].

The system is imagined to cycle along a trajectory in the shape of a tilted figure “8” (Fig. 1). Each cycle consists of four stages: r – new beginning and growth; K – equilibrium, conservation and *status quo ante*; Ω – dissolution and confusion; and α – reorganisation and innovation. The r -stage is mainly concerned with the instauration of the new and abolishment of the old; the K -stage is about controlled development and maintenance of system function; the main concern in the Ω -stage is survival; while the α -stage is about renewal, regeneration and reorientation [1]. Additionally, the r - and K -stages are characterised by many small-scale cycles – sub-trajectories “representing modular experimentation within the overall upward system trajectory” [1; p.2]. These small-scale cycles are visually represented by many small loops in the shape of figure “8” (Fig. 1).

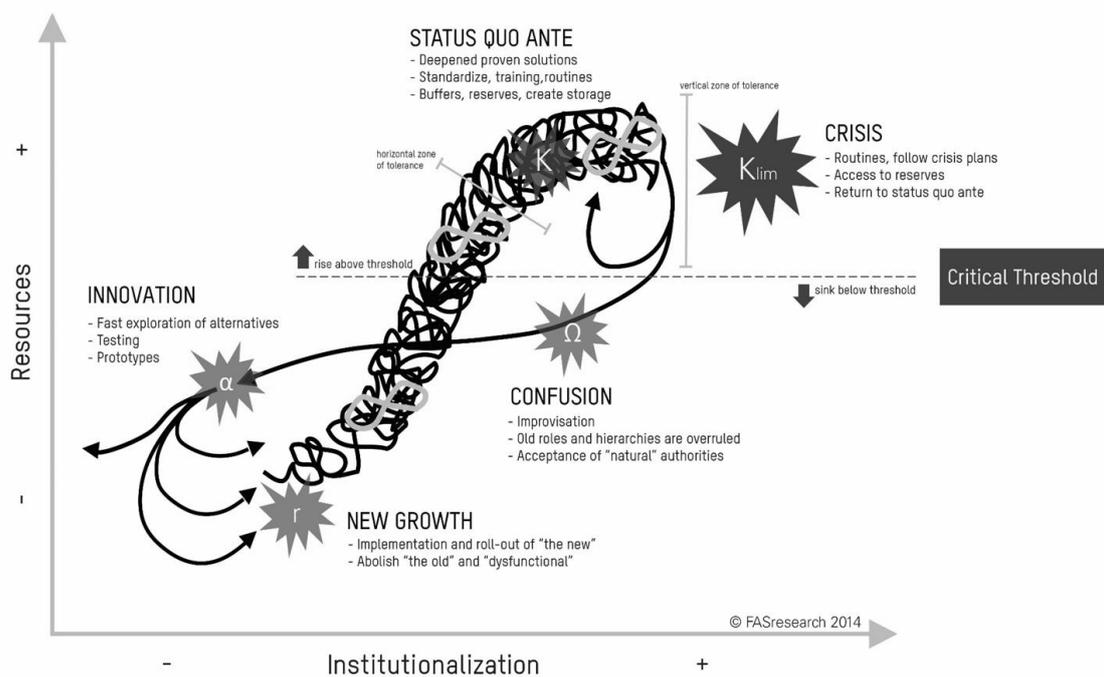


Figure 1. The model of resilience in social systems [1].

Each of the stages is also associated with its corresponding “trap” that endangers the system’s cycling. The main trap of the r -stage is the “poverty trap”, which “occurs when a system cannot access enough activation energy to reach a state where positive feedbacks drive growth internally” [1; p.2].

The trap of the K -stage is the “rigidity trap”, wherein “a system becomes so refined in its processes that there is little room for further innovation” [1; p.3]. The rigid system becomes brittle and vulnerable to disturbances. Additionally, there is a critical threshold K_{lim} associated with this stage (Fig. 1). The systems that sink below this threshold are able to persist through a crisis. The systems that continue to “overshoot” the threshold K_{lim} presumably continue within the K -stage until the next crisis, at the expense of getting too big and brittle making surviving Ω -stage less likely. Such systems are deemed to engage in a “relentless resource acquisition” [1; p.4] and excessive spending, leading to a danger of overstretch.

The trap of the Ω -stage is the “dissolution trap”, manifested in an inability of the system to survive the omnipresent confusion. Finally, inability to reorient the system in the α -stage leads to the “vagabond trap”, i.e. “circling compassless, without moving into the r -stage of growth” [1; p.4].

Fath, Dean and Katzmaier claim that “resilience is linked to some dynamic between slow variables that represent the underlying structure of the system and fast variables that reflect dynamics in the present” [1; p.6]. They further hypothesise that, in social systems, social cohesion is the key factor that “represents the interplay between fast and slow variables” [1; p.6]. Another important factor are small-scale disturbances in the *K*-stage, which “should be encouraged (...) because they contribute to the adaptive capacity of the system and its ability to innovate” [1; p.7].

Finally, Fath, Dean and Katzmaier propose that a resilient system “is one that is able to navigate successfully through each stage of the cycle, adopts a new regime that shares important features of the previous regime, and continues to satisfy a set of goals as defined by members within that organization” [1; p.8].

CCMS'S RESPONSE TO COVID-19 PANDEMIC IN TERMS OF THE MODEL

K-Stage Prompted by the spread of COVID-19 pandemic in China, the Croatian Government started taking preparatory measures in January 2020. On 13 February, the Government established the national Civil Protection Headquarters (CPH) to coordinate all services involved in prevention of the COVID-19 pandemic in Croatia [15]. However, public interest in all these activities was relatively low and the pandemic was generally not perceived in public as a serious threat at the time. The national crisis management system was yet not under stress and it continued to operate as usual. Hence, we can safely assume that, in terms of the previously described model, the system was in the pre-COVID *K*-stage, aptly described as *status quo ante*.

CYCLE 1

Ω-Stage The situation suddenly changed on 25 February, when the first case of COVID-19 infection in Croatia was confirmed and the number of new cases¹ started to rise slowly but steadily in the following days [23] (Fig. 2). Public opinion changed swiftly. Fear and even panic started to rise [24]. Shelves in supermarkets were emptied rapidly, which urged the Prime Minister to calm the public down [25]. Despite the appeals, the strain on some resources was considerable. In particular, there were shortages of face masks and disinfectants.

The CPH started its daily sessions after which press releases were issued [15, 26]. On 5 March the Minister of Health declared the danger of COVID-19 epidemic in the whole Republic of Croatia [15]. The CPH and the Ministry of Health introduced several packages of measures, mostly related to crossing the state borders, international travels, and rules of procedure for healthcare professionals [15]. All kindergartens, schools, and universities were closed on 16 March, and classes were continued remotely via television and online platforms [27]. On 19 March the CPH introduced one of its most comprehensive sets of measures that included “suspension of social gatherings for more than 5 persons; suspension of all cultural activities; suspension of the work of cafes, bars and restaurants (except delivery), as well as of services that include direct contact with clients (hairdressers, beauticians, barbers, pedicures, massage parlours, saunas, swimming pools); suspension of all organised sports activities and contests; suspension of all workshops and courses; suspension of religious gatherings” [28; p.3]. Fearing that existing hospital capacities might not be enough, the CPH authorised setting up provisional hospitals in sports halls and large military tents [29].

The main question that public health decision-makers were grappling with was: “What’s next?” [30]. And, next came an earthquake of 5,5 magnitude on the Richter scale that struck the Croatian capital of Zagreb on 22 March, leaving one person dead, 26 injured, and more than 26 000 houses damaged, 1900 of which were inhabitable [31-33]. The Ω -stage of

confusion reached its apex. On 23 March, the CPH restricted free movement. Citizens were prohibited to leave their city or municipality of residence, except with special permissions [34]. Although, as we already remarked, various restrictive measures had been brought into force even earlier, it was 23 March which in everyday parlance became known as “the beginning of lockdown”².

α -Stage Having most measures in place, the main task for the CPH in the ensuing period became fine-tuning of the measures. Indeed, “[t]he success of navigating through the fast-moving α -stage is largely a function of system development and decisions made in prior stages” [1; p.4]. The fine-tuning required careful monitoring and evaluation of measures’ implementation. Some of the measures proved to be overly restrictive and required relaxation. For example, although green markets were closed on 22 March, they were reopened, under a special regime of operation, as soon as on 8 April [35], as it became evident that they do not pose danger to public health and that it would be wasteful to let large supplies of fresh and healthy food perish. Similarly, the model of organised convoys for transiting freight vehicles was abandoned as soon as it became evident that it was overly restrictive [36]. Some measures, on the other hand, were strengthened. For example, permissions to travel between cities, municipalities and counties were found to be often misused, so the system of their issuing was streamlined, and their maximum validity period shortened from 30 to 14 days [37].

Although the leadership was mainly top-down – from the national to regional and other local levels – there were also examples of bottom-up initiatives. For instance, quarantines were introduced at the initiative of some local communities, such as Murter and Betina, where outbreaks were particularly severe [38]. Some local self-government units decided to close promenades and walkways for fears of outbreaks at such places [39].

Although the economic sphere is not at the focus of this article, we need to emphasise that most of reorganisation and innovation, predominantly but not only in the α -stage, took place in businesses, particularly small ones. Many small agricultural producers were, for example, forced to start selling their products online, as this proved to be the only way to find customers, under the lockdown [40]. As one commentator observed, “one small light in the coronavirus pandemic is that it has forced creativity in order to sustain businesses, and Croatian farms that formerly only had a presence at their market stands now belong to large online communities” [41]. Again there were examples of emergent bottom-up leadership, as some local self-government units, such as the City of Križevci, helped small agricultural producers to establish a web-platform over which they could offer their products and services to a wide range of customers [42].

There were fears that the Zagreb earthquake “would accelerate the spread of the COVID-19 epidemic in Croatia since the earthquake (...) triggered migrations to other parts of the country” [31; p.2]. There were also fears that natural human need for social support in times of distress would overrule restraint and physical distancing needed to prevent the spread of the virus. Fortunately, such fears remained unsubstantiated as there was no significant increase in new cases of disease in the earthquake’s aftermath [31].

After reaching the peak of 96 on 1 April, daily number of new cases in Croatia started to decrease (Fig. 2). By 22 April, 5-days moving average of daily new cases dropped to around 30, and it was estimated that the reproduction number R – the expected number of additional cases that one case will generate in a population, on average, over the course of its infectious period [43] – dropped to approximately 0,8. It was also claimed that it had been below or around 1,0 for weeks already [44]. When R is below 1,0, it indicates that the number of cases is decreasing, meaning that the spread of the virus is effectively contained. On 23 April the Government announced gradual relaxation of restrictions in three phases [45].

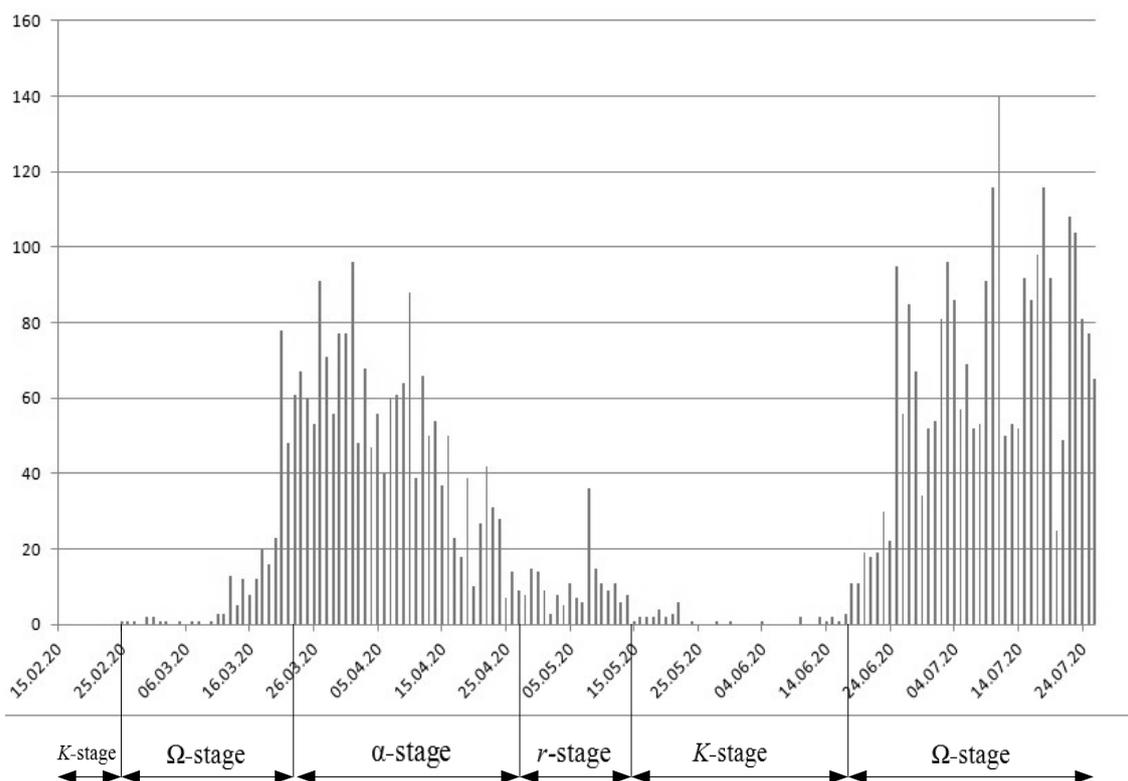


Figure 2. Daily new cases of COVID-19 in Croatia by stages. The data on daily numbers of new cases in Croatia were collected by the authors from public sources, whenever possible from press releases of the CPH.

r-Stage The “new beginning” started on 27 April with the reopening of most retail stores, services, public transport facilities, libraries, museums, and galleries [45]. By the middle of May, 5-days moving average of daily new cases dropped below 10 (Fig. 2) and most of the measures were lifted.

K-Stage For a monthly period between mid-May and mid-June, the number of daily new cases remained below 5, the only minor exception being 22 May, when 6 new cases were recorded (Fig. 2). General public perception was that the danger is over and that life might go back to normal. Official recommendations related to keeping physical distance and using disinfectants were still in place, but most of the people, particularly younger ones, stopped following these advices. During this period, the authors of this article several times found hygiene stands with disinfectants in public places, such as shops, being emptied rather than full, and nobody seemed to care about it. Citizens were supposed to adapt to a new regime of co-existence with the virus or “the new normal”, but they returned to “the old normal”, the *status quo ante* in the literal sense. It was as if the success of the lockdown lulled them into a false sense of security.

It would be wrong, however, to blame only ordinary people for such a state of affairs. The CMS, headed by the CPH, was not pro-active enough in its advisory and educational roles. Two additional factors were involved in complicating the situation. First, tourist season, which in Croatia reaches its highest points in July and August, was approaching, and it was widely viewed as a chance to compensate for at least some of the economic losses incurred by the lockdown. It was also believed that too much talk about COVID-19 dangers in public could spoil this chance. And second, parliamentary elections were scheduled for 5 July, and it was again deemed inappropriate to remind the population of COVID-19 dangers prior to the national “festival of democracy”. Taking it all together, it is not surprising that the new increase in cases of COVID-19 infection caught everyone somewhat off-guard.

CYCLE 2

There is some uncertainty as to whether an increase in the number of new cases of COVID-19 infection in Croatia in the second half of June reflects a continuation of the first wave or the beginning of the second wave. According to the epidemiologist Bernard Kaić, this question is of only a limited importance [46]. We decided to call this new increase a “second cycle”, as it indeed corresponds to a second loop along the system’s adaptive trajectory.

Ω-Stage The number of new cases started to rise again in mid-June (Fig. 2). On 3 July, the maximum of 96 from the first cycle was achieved again, and on 11 July, the new maximum of 140 was recorded. The total number of cases grew from around 2 250 after the first cycle to around 4 000 in mid-July. The authorities made it clear that there will be no lockdown anymore because of its destructive economic consequences [47]. However, the CPH had to introduce some measures again. For example, face masks were made mandatory in numerous indoor settings, such as public transport, shops, banks, post offices, and various other services [48]. At the time of this writing, the question of what’s next becomes all the more prominent once again. Summer does not seem to have diminished the virus’ strength as was expected, and the worries of what the autumn flu season may bring have only intensified.

DISCUSSION

RESILIENCE

When the number of COVID-19 cases started to rise in early March, the uncertainty was also rising. The CPH and other authorities were not sure whether existing healthcare capacities will be enough and terrifying scenes from Italy served as examples of what can happen in the absence of timely and decisive action. Hence a lockdown was imposed. It was hard to bear economically and psychologically [49, 50], but it successfully curbed the spread of the pandemic. By the end of the first cycle in mid-June, Croatia had around 2 250 cases and 107 deaths in total, or around 550 cases and 26 deaths per million of inhabitants. These moderate numbers meant that most of the set-up provisional hospitals, fortunately, proved to be unnecessary.

The CCMS has successfully completed one cycle along the adaptive trajectory, avoiding all the potential traps. However, the very success of the lockdown lulled most people into thinking that the danger was over and that the return to the previous way of life was possible. A resilient system is not only the one “able to navigate successfully through each stage of the cycle”, but also the one that “adopts a new regime that shares important features of the previous regime, and continues to satisfy a set of goals as defined by members within that organization” [1; p.8]. While the CCMS fulfilled the first condition, the second one is yet to be accomplished. The system has to learn to co-exist with the virus in a new regime that will simultaneously enable a life of relative normalcy *and* contain an excessive spread of the virus. One of the most delicate tasks will be balancing between reasonable interpersonal contact and avoidance of infection. The amount of public outcry that accompanied the attempts of the CPH to regulate social events such as wedding parties shows how demanding this task may prove to be [51].

SOCIAL COHESION

We concur with Fath, Dean and Katzmaier’s proposal [1] that social cohesion is the key factor in social systems’ resilience. Indeed, there is evidence of strong social cohesion during the first cycle, and particularly in its α -stage. The majority of citizens supported measures taken by the CPH during the lockdown [52]. This, together with the success of the lockdown, fits well with Fukuyama’s [53] proposal that “the thing that determines a country’s resistance to the coronavirus” is “whether citizens trust their leaders, and whether those leaders preside

over a competent and effective state". Rothstein [54] explained differences in success in containing the virus between Nordic countries and Italy by higher levels of social and political trust in Nordic countries. As social cohesion includes trust [55], these findings are in agreement with the above cited Fath, Dean and Katzmaier's hypothesis [1].

There were also many examples of social solidarity during the first cycle. Bad Blue Boys, an ultras group of supporters of the football club Dinamo Zagreb, assisted in preparations of the Dubrava Clinical Hospital for admission of COVID-19 patients, launched an action to help elderly, infirm, and chronically ill fellow citizens who needed assistance during the pandemic, and were among the first to help the Maternity Hospital in Petrova Street after the Zagreb earthquake, rescuing pregnant women from damaged buildings and carrying new-borns in incubators to safer hospitals [56, 57]. Thousands of volunteers, including those organised in a Facebook group "People for other people"³, offered to provide aid to elderly and other people in need during the lockdown [28]. Some commercial web portals offered free-of-charge promotion to small businesses that were delivering food and other necessities [58]. Many small businesses were delivering food free-of-charge to exhausted healthcare workers. In cities, people were coming out at their balconies, singing, clapping hands, and cheering in expressions of mutual support and solidarity with professions who were bearing the brunt of the COVID-19 crisis.

However, as the first cycle was subsiding, there were less such displays of social cohesion, and polarisation of society became particularly apparent prior to the parliamentary elections. Political rallies replaced all-together chanting from the balconies. Allegiance of members of the CPH to the ruling party likely contributed to the lowering of trust in their decisions among voters of other parties. As of this writing, the President, who was elected as a candidate of the strongest opposition party, as well as several other opposition parties are questioning the constitutional status of the CPH [59]. While the legal status of this body certainly needs to be clarified, it is questionable whether the high point of the second cycle is the right time for bringing its legitimacy into question. Some observers, such as Marko Kutleša, Head of the Intensive Care Unit at the University Hospital for Infectious Diseases "Dr. Fran Mihaljević" in Zagreb, hold that many actors in this crisis, including the CPH, try to score political points and misuse the situation for public relations purposes [60]. If this is the case, then it is no wonder that social cohesion suffers. Follow-up studies can investigate more deeply the factors of social cohesion such as trust, inclusion, shared values, and strength of social relations to assess enhancing its capacity for just such crisis moments.

Weakened social cohesion may be one of the reasons why the second cycle was so intense in terms of new cases. In future research, our so far largely anecdotal evidence should be backed by more rigorous measurements [55] and/or use of aggregate indices of social cohesion [61, 62].

LEADERSHIP

We also tend to agree with Fath, Dean and Katzmaier's [1] emphasis on the role of leadership in the Ω -stage. Indeed, the role of the CPH and other authorities was crucial in the Ω -stage of the first cycle, and the lack of reliable leadership has so far characterised the Ω -stage of the second cycle. This may be related to the fact that the main direction of control during the lockdown was mostly top-down – from the CPH and other authorities toward local self-government and citizenry – whereas in the second cycle the locus of responsibility shifted toward the individual level. In the latter case, the role of emergent leadership – "actors not tasked with leadership roles [who] informally assume key positions during crisis" [1; p.3] – should be crucial.

However, no clear emergent leadership appeared during the second cycle so far, although there are some promising examples. An example of bottom-up initiative emerged in the tourism sector where it was articulated that some more stringent measures, such as mandatory

face masks in indoor public spaces, would actually do more good than harm to the sector [63]. The CPH of the Istria County has been among the most active regional CPHs since the beginning of the first cycle. Depending on the local circumstances, they asked from the national CPH to strengthen or relax various measures in their county and most of their proposals were approved [64, 65]. As of this writing, the CPH of the most eastern Croatian county – the Vukovar-Syrmia County – requested from the national CPH to ban all the wedding parties in the county, except those attended by only closest family members, for at least two weeks, as wedding parties proved to be places of major outbreaks in the county so far. The national CPH accommodated their request [66]. A group of enthusiastic professors from Osijek and Slavonia is working on a proposal to include various topics on biosecurity and protection from COVID-19 in school curricula [67]. Future successes in fighting the pandemic may well depend on a shift toward more such locally instigated measures and initiatives.

THRESHOLD K_{lim}

Perhaps the most obvious candidate for K_{lim} , in the context of our application of Fath, Dean and Katzmaier's model [1], is the value of the reproduction number $R = 1,0$. Overshooting this threshold means that the spread of the virus is not under control, and there is a danger of resource overstretch. Keeping R below 1,0, on the other hand, means that the spread of the virus is contained. The problem with R is that it is not easily calculable – its calculation requires considerable epidemiological expertise and there is a time lag in results⁴. As a quick and easy rule of thumb, the number of new cases per 100 000 inhabitants can be used. For example, the number of 10 new cases per 100 000 inhabitants in the last 14 days is used by Slovenian epidemiologists as a threshold for “epidemiologically safe countries”, whereas the EU proposed a somewhat more lenient threshold of 16 [68].

Whatever the value of K_{lim} is taken to be, the major discrepancy between the original model [1] and our application is that descent below the K_{lim} threshold is in the original model deemed to happen in the K -stage, whereas in our application this occurs later, in the Ω - or even α -stage. Perhaps a clearer specification of what K is supposed to denote in the original model would help. Currently, it seems that K is some kind of a proxy for a strain on system's resources, and as such, both R and the number of new cases per 100 000 inhabitants are plausible. If we are to choose candidates for K that are determinable as early as in the K -stage, we would pick something like the number of tests conducted or the number of epidemiologists available per 100 000 inhabitants, for these seem to be crucial for early warning and prevention. Note that these parameters are inverse measures of strain on resources – generally, the higher they are, the lower the strain that can be expected in later stages. However, neither the tests nor the work of epidemiologists come for free, but more detailed considerations of cost-effectiveness of those resources are beyond the scope of this article.

SMALL-SCALE DISTURBANCES

We have already mentioned the importance that Fath, Dean and Katzmaier ascribe to small-scale disturbances which “represent multi-level interactions that promote learning of the system and allow upward flows of information (...) through smaller, faster sub-systems to the larger, slower system” [1; pp.7-8]. The small-scale disturbances in our conceptualisation would be small, local outbreaks that arise in the K -stage, represented by small numbers of daily new cases between mid-May and mid-June in Figure 2. If they are successfully repressed, the chances of future major outbreaks are diminished. These small, local outbreaks can be regarded as a sort of “training” of the system for possible larger emergencies.

The “smaller, faster sub-systems” in our conceptualisation would be regional and local, i.e. county-, municipal- and city-level, CMSs, headed by local CPHs, the task of which is to monitor

the local situation, react as quickly and efficiently as possible to the local outbreaks, and stifle them [69]. We also relate these smaller sub-systems to the small-scale cycles of Figure 1.

We can “go local” even further to include individual-level behaviours and decisions – such as physical distancing, wearing face masks, using disinfectants, getting tested when ill, etc. – as even “smaller, faster sub-systems”. In fact, it can be argued that this is the ultimate “local scale” which can address the problem. We also do not feel obliged to limit these small-scale cycles to the r - and K -stages only, as they seem to be present in all stages.

It is also tempting to consider how to extend this analysis in the other direction – toward supra-national levels. Indeed, it is imaginable that the big cycle from Figure 1 represents the EU level, and the smaller cycles – the level of individual member states, Croatia including. Again, we can go even further and think of the world as the ultimate systemic level, and the individual countries, or supra-national units such as the EU, as the smaller cycles.

COMPARISON WITH “THE HAMMER AND THE DANCE”

Another popular and often cited model dealing with the COVID-19 pandemic is “the hammer and the dance” [70]. In this metaphor, “the hammer” represents “quick and aggressive” [70] measures, such as lockdown, to curb the spread of the virus, lower R below 1,0, and buy the time needed for a full preparation of the CMS. The “hammer” is followed by the “dance” – a “months-long period between the Hammer and a vaccine or effective treatment” [70], during which a combination of less restrictive measures is applied as needed: testing, contact tracing, quarantining, isolating, public education on hygiene and physical distancing, bans on large gatherings, and so on. The ultimate goal of the “dance” is to keep R below 1,0.

“The hammer and the dance” is often visually presented as initially big wave of new cases, followed in time by a number of wavelets (Fig. 3). The earlier noted inability of the CCMS to adopt a new regime after the success of the lockdown is reflected in a discrepancy between the graph of the new cases in Croatia in time (Fig. 2) and the prediction of “the hammer and the dance” (Fig. 3) – the second wave in the Croatian case is not a wavelet, as “the hammer and the dance” would predict, but a wave of a magnitude comparable to the first one, if not even larger (Fig. 2). Even if “the hammer and the dance” is more a description of an ideal case than the real-world ones, the second wave in the Croatian case still seems to be too large.

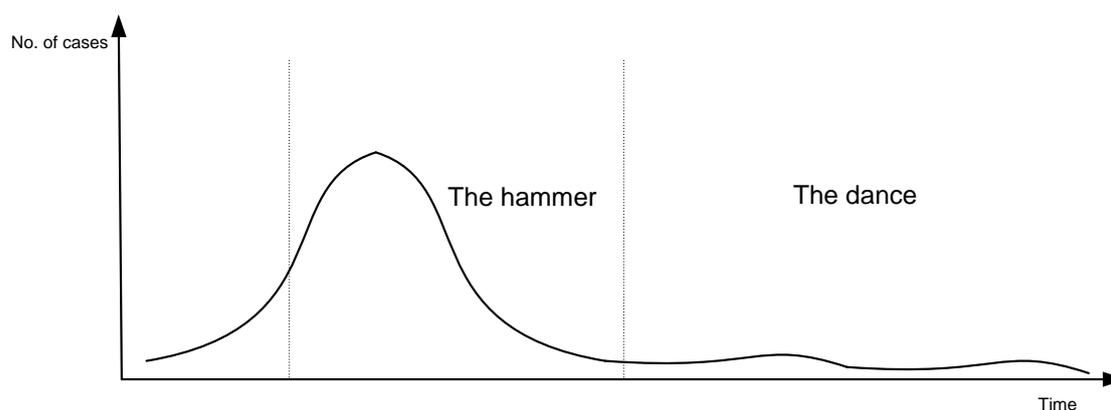


Figure 3. A sketch of “the hammer and the dance” (adapted from [70]).

The main difference between “the hammer and the dance” and the model used in this article is that the scope of “the hammer and the dance” is narrower. “The hammer and the dance” model is almost all about the trends in number of cases in time. It does not address wider, systemic notions, such as resilience, social cohesion, multiple sub-systemic levels, and scales. The simplicity of “the hammer and the dance” makes it suitable for public communication,

but it also hampers the model's ability to convey the underlying complexity of CCMSs. This is not to say that the calculations behind “the hammer and the dance” are necessarily simple. On the contrary, they may be quite complex. However, the model itself serves as a sort of interface between the general public and the background calculations, the complexity of which is abstracted into an appealing metaphor expressed in only two words of everyday language – “the hammer” and “the dance”. Fath, Dean and Katzmaier's model, on the other hand, faces the underlying complexity head-on, albeit not by complex calculations, but by a description using the terminology of complex systems theory. The downside of such an approach, however, is that the model is not easily communicated to non-specialist audiences.

CONCLUSIONS, POLICY IMPLICATIONS, EXTENSIONS AND FUTURE WORK

Returning to the aim of the analysis stated in the Introduction, we conclude with what we have learned about the CCMS from the application of Fath, Dean and Katzmaier's model. The first four conclusions have clear policy implications (PI), while the latter three are more closely related to modelling considerations:

- The CCMS successfully completed one cycle of the model, which is an important first step toward system's resilience. However, it can also be argued that the first cycle is easier to complete than the latter ones due to novelty. PI: Successes of the lockdown, or – more generally – any short-term successes in this crisis, should not lull anyone into complacency. This pandemic can only be overcome by long riders.
- The system is still searching for a new regime that will simultaneously enable a life of relative normalcy and contain an excessive spread of the virus. PI: Getting through a second cycle will take more willpower, but people have, hopefully, also learned something. At the very least, they have learned that they are not helpless in the face of the pandemic. Lockdown can successfully contain it, albeit at high economic and psychological costs. Somewhat paradoxically, learning that they are not helpless helped people also to unlearn some of the beneficial routines they had adopted during the lockdown – distancing, wearing face masks, using disinfectants, etc. Re-learning and applying those routines is a must.
- Social cohesion during the first cycle was strong and then it weakened. Strengthening social cohesion might facilitate the search for a new regime. PI: The rules of distancing, wearing face masks and isolating should be equal for all, be they politicians or ordinary people. The rules should be equally applied to wedding parties and other large festivities, including election victory celebrations. Equal treatment is important for strengthening both political trust and social cohesion. The COVID-19 crisis cannot be solved by imposing the will of any political grouping or majority vote. We need to make sense of this crisis together.
- While leadership during the first cycle was top-down, more bottom-up, emergent leadership is needed in the search for a new regime. PI: Bottom-up initiatives should be not only approved when they occasionally appear, but also systematically encouraged. Leadership should also be credible. Leading by example provides more credibility than merely pointing out other people's faults. Unity of purpose is also important. When the same leaders, who were justifying strict lockdown, a month or so later become reluctant to introduce any measures, this sends an inconsistent and confusing message. Such changes of policy need to be clearly and patiently explained to citizens, and not merely glossed over.
- The reproduction number and the number of new cases per 100 000 inhabitants are faster-moving candidates for the measure K of strain on resources, indicative of danger of resource overstretch. The number of tests conducted and the number of epidemiologists available, per 100 000 inhabitants, are slower-moving candidates for K .

- Small, local outbreaks represent small-scale disturbances that promote learning and allow upward flows of information through local – county-, municipal- and city-level – CMSs to the national CCMS. The analysis can be extended toward the individual level as the ultimate “local” scale, as well as toward supra-national and global levels as higher systemic scales.
- Fath, Dean and Katzmair’s model conveys the underlying complexity of CMSs better than the simpler “hammer and the dance” model. The latter is, however, better suited for public communication.

This article is a case study in analysing CMSs’ responses using systemic resilience models. In terms of Figure 1, our effort can be likened to only one of the small-scale cycles in the *K*-stage of systemic resilience models development and validation. Our case study needs to be extended in terms of modelling approaches, space and time.

There exist systemic resilience approaches other than the panarchy model used in this study. These include, for example, ecological information-based networks and models using statistical evidence of resilience [17]. Further research is needed to see whether such alternative approaches can also be used in CMSs’ response analyses.

There have been more than 200 countries, territories, and international conveyances, such as cruise ships, afflicted by the COVID-19 pandemic worldwide [71]. A comparative study extending the framework outlined in this article should include a reasonably large sample of these. The sample might include developing nations, which, in addition to pandemic-related issues, face many other serious problems, such as lack of resources, political instabilities, armed conflicts, migrations and refugees-related problems, and already existing diseases. The earlier mentioned extension of the analysis toward supra-national levels should also be tried in such a comparative setting⁵. Of course, this would require far larger resources than what we had at disposal, and would be ideally addressed by an international project consortium.

Our study should also be extended in time. It remains to be seen whether systemic resilience models can account for CMSs’ responses on larger time scales, including possible multiple pandemic waves.

REMARKS

¹Whenever we speak of the number of cases, we mean the number of *detected* cases, which almost certainly underestimates the *true* number of cases, but it is difficult to assess by how much.

²Dates of beginning and ending of each stage are approximate. In some cases we chose dates that were particularly remembered in collective memory as “the day of the first COVID-19 case in Croatia” or “the beginning of lockdown”, while in other cases these dates were more arbitrarily chosen. Indeed, it could be argued for each stage that it began or ended a few days earlier or later, without any consequences for our main claim – that the sequencing of events as they happened in the real world generally corresponds to the sequencing of stages as described by Fath, Dean and Katzmair [1].

³The original Croatian name of the Facebook group is „Jedni za druge“.

⁴A more general way to pose the question of the time lag is what characteristic time is needed to observe on an aggregate level the effects of a change in contagion at the level of individuals.

⁵Extending the research framework toward supra-national levels might help address complex global-scale problems, such as healthcare supply chains management, which may be particularly important for developing countries. For example, hydroxychloroquine (HCQ), which is known to be an effective treatment for patients with autoimmune disorders, has also been used in COVID-19 treatment. Some developing nations are currently in danger of HCQ shortages and putting at risk patients depending on this medication, as demand for HCQ increases and high-income countries order additional supplies for potential COVID-19 prophylaxis [72].

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DENTAL TOURISM AND BUSINESS RISKS: THE EXAMPLE OF THE REPUBLIC OF CROATIA

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DOI: 10.7906/indecs.18.4.3
Regular article

Received: 4 August 2020.
Accepted: 14 September 2020.

ABSTRACT

Dental tourism in the Republic of Croatia in the last ten years has proven to be a model of extremely profitable business in dentistry but at the same time also a very risky one. In the present day, we can find only one research article dealing with dental tourism in the Republic of Croatia. There is a minimal number of scientific and professional article by Croatian researchers and only a rare professional publication. To date, not all aspects of business/operations in dental tourism in the Republic of Croatia have been researched, including business risks. This article provides an overview of the status of dental tourism in the Republic of Croatia with an overview of the foreign market's potentials and a focus on the Italian market. It explains the modes, advantages and disadvantages of advertising dental products and dental tourism services in the Republic of Croatia on social networks, and presents the business/operations of Croatian dental clinics as a result of investment in advertising and communication. The Croatian dental tourism market is analysed in terms of difficulties currently encountered by dental clinics due to the consequences of the COVID-19 pandemic, as a business risk, i.e. the recent crisis. As a result this article sets out and explains the steps to be taken to mitigate the impacts and continued the development of dental tourism in the Republic of Croatia in these circumstances.

KEY WORDS

dental tourism, business risks, development, advertising, Republic of Croatia

CLASSIFICATION

JEL: M37, M38, Z30, Z32, Z39

INTRODUCTION

The development of dental tourism in the Republic of Croatia, and throughout the world, has drastically accelerated within possibilities of advertising on social networks. This was also the case in those Croatian dental clinics that are geographically near or along the state border, which has long led to the arrival of foreign patients, especially those from Italy. Advertising on social networks has helped these clinics to promote their services in the countries from which patients come as well as in countries that are potentially interesting for further business development. Those who recognized this, and were among the first to take advantage of such opportunities, gained a significant advantage over the competition, and in a short time achieved the accelerated development of their clinics. However, few paid enough attention to the risks that arise with a sudden expansion and conquest of a foreign market. Today more than before, and due to the recent pandemic of COVID-19, the risks of such business have come to the fore, although there have been severe indications that in the development of dental tourism when it comes to investment and expansion, special care should be taken.

DISCUSSION

WHAT IS DENTAL TOURISM

Dental tourism is defined by the American Dental Association in 2009 „*as the act of travelling to another country for the purpose of obtaining dental treatment*“ [1]. Dental care is a subset of medical care where tourism has increasingly become prominent [2, 3]. It has been one of the popular services sought by tourists, well known in professional circles and well covered in the media [4, 5].

Countries reportedly are known for offering dental tourism services are Hungary, Mexico, Poland, Romania, Bulgaria, Croatia, Argentina, Costa Rica, Peru, Thailand, Malaysia, Singapore, India, Phillipines, Korea [4-10].

Dental tourism, as a form of medical tourism, is based on providing equal or more valuable dental services outside the home country at more favourable prices with added value in the form of tourist offers and arrangements. Patients go to a foreign country for a cheaper dental service, but also because in the home country certain services are not available to them or are not at the quality level of services of foreign clinics they plan to visit. The decision to go to a foreign country, where the services are more favourable and of better quality also avoids the long wait for certain procedures in the home clinics, that are covered by the basic health care system. In most cases, a more favourable price of services is the main reason, and by including tourist activities in the entire arrangement, there is an increased desire to go to a foreign country, especially if it's recognized as an attractive tourism destination.

RESEARCH OF DENTAL TOURISM IN THE REPUBLIC OF CROATIA

In the Croatian scientific and professional literature, there is very little representation of research related to dental tourism. The only scientific research conducted in Croatia on dental tourism is „*Perception of Croatia as a destination for health tourism in the intermediary market – qualitative research. Final report*“ prepared in 2018 by the Institute for Tourism from Zagreb on behalf of the Croatian National Tourist Board [11]. This research focuses primarily on health tourism in Croatia, while only partially relying on dental tourism, although it accounts for the largest share of health tourism in Croatia. This study identified obstacles or constraints to the more substantial development of health tourism in Croatia. The primary problem is poor airline connectivity with key markets, which is analyzed in the example of dental tourism in Hungary, which relies heavily on low-cost air connections with the United Kingdom.

Further, two diploma theses, thoroughly deal with the issue of health and dental tourism in Croatia. The article „The future of health tourism in the Republic of Croatia“ explains the problem of difficult development of health tourism in the Republic of Croatia, including dental, due to insufficiently harmonized laws of competent ministries, which should legally regulate the development of health and dental tourism in the Republic of Croatia [12]. „Development of dental tourism in Croatia“ is a paper that defines health tourism and interprets the differences between health, medical and dental tourism, which created an appropriate starting point for understanding the bigger picture and understanding the position and role of dental tourism in Croatia [13].

Here we highlight the first bilingual, English and German guide to dental tourism in Croatia, „Croatia – Dental Tourism 2013/2014. Kroatien – Dental Tourismus 2013/2014“ [14], a marketing project which lists all the benefits of using dental tourism services in the Republic of Croatia, with the prices of services and the possible use of various tourist offers (accommodation, cultural, gastronomic) during patients stay in Croatia.

Finally, although it's not a scientific field, due to their number we mention standard texts available on the Internet that describe dental tourism in Croatia. They have mostly been published on dental clinics's web sites with attention to get a better position on search results on Google if users search for keywords such as dental tourism, dental implants abroad, dental accommodation abroad, and other keywords related to dental tourism. . An example of one such text is that of the Croatian clinic „Dental Smile Academy“ from Zagreb which wanted to attract English patients [15]. The document provides essential information on prices of services in the Croatian clinic with comparative costs of the same services in the UK, describes the quality of materials used and dental services compared to competing countries, emphasizes superior equipment and technology, describes in detail accommodation, geographical position of the clinic and local gastronomic offer. Although such texts do not deal with analysis with dental tourism from a scientific and professional point of view, they can be perceived as credible presentation of Croatian clinics that invest in the development of dental tourism and attracting foreign patients.

In the light of the aforementioned, we can find few available research and scientific, i.e. professional and popular papers on dental tourism in the Republic of Croatia, thus this article is one of the few Croatian scientific papers that more comprehensively explains the development of dental tourism in the Republic of Croatia and describes its current situation, advertising services in dental tourism, business risks and procedures and lastly measures that should be taken to avoid risks or at least reduce them with aim of maintaining a successful business.

STATE OF DENTAL TOURISM IN THE REPUBLIC OF CROATIA

Apart from being known as a tourist destination, Croatia has recently become increasingly popular as a destination for dental tourism due to the low prices of dental services. In addition to the sun and the sea, tourists have the opportunity, at extremely affordable prices, to fix their teeth during a visit to Croatia. Dental services such as implantology, prosthetics, oral surgery and orthodontics in Croatia are several times cheaper than in the countries of the European Union, and the level of quality of services is the same or even better.

Although some European Union countries have a much higher standard than others, it is becoming increasingly difficult for people to cover the costs of medical services, especially when it comes to the health of their teeth. Therefore, an increasing number of people in the European Union are considering solving their dental problems outside their country. Lower costs of education and training of staff, opening an office and real estate are just some of the

reasons why dental prices are lower in Croatia than in European Union countries. Croatian dentists use the most modern dental equipment in their modernly equipped surgeries and follow the development of science and technology. Therefore, a large number of Croatian dentists have recognized dental tourism as an additional source of income.

When it comes to dental services, implantology, prosthetics and oral surgery are the main reasons why foreigners come to Croatia. In Croatian dental clinics, they receive quality and fast care, individual approach and top service. Patients get a new and more beautiful smile in a short period of time, at affordable prices, while in their countries they would pay a similar service at a much higher price. Also, they have the opportunity to get acquainted with the natural and cultural beauties and gastronomy of Croatia.

In Croatia, dental tourism is a relatively new branch of the economy. Although some clinics have long-term relationships with foreign patients, providing them with dental services for the last 15 years, in recent years, we have witnessed the organized development of dental tourism in Croatia. Clinics from Istria and Kvarner in cities such as Pula, Poreč, Rovinj, Opatija and Rijeka have been doing business with Italian patients for about 30 years. Italians also visit clinics located further south, those in central Dalmatia, especially in Split, which is well connected with Italian ports by waterway. Italian patients as tourists, throughout the year, regularly visit Croatia. Many citizens of the Republic of Slovenia also use services of Croatian dental clinics, those located in northern Croatia, as well as German and Austrian patients who have also been coming to Croatia for decades. A smaller number of Croatian dental clinics are also visited by patients from other European and overseas countries. However, until about 15 years ago, these visits were based mainly on the personal recommendations of acquaintances, friends and relatives. Marketing activities were below today's level, it was not possible to reach a more significant number of potential foreign patients, and thus not to develop dental tourism more seriously.

Although there are dental clinics throughout Croatia that attract foreign patients, they are most numerous in Zagreb, Rijeka and Split. Interestingly, the development of Zagreb dental clinics in the last ten years has drastically changed the trend of foreign patients going to coastal and Dalmatian clinics. It should be taken into account that the accession of Croatia to the European Union has simplified the movement between the Member States, which has further brought Croatian clinics closer to Western European countries, i.e. patients.

Dental tourism in Croatia is still developing. It currently facing a major global problem and challenge that will determine his future development, which is further discussed in this article.

PRODUCTS AND SERVICES OF CROATIAN DENTAL CLINICS

To bring Croatian clinics closer to economically more robust foreign markets, the critical elements of the offer are those dental services with the most significant difference in prices, which are also the most profitable. These are implantology, oral surgery and prosthetics. Croatian dental clinics also offer other dental services such as, for example, periodontology, endodontics, conservatives and aesthetic procedures, and complete dental services as well. However, a strong emphasis has been placed on implantology primarily because of global price differences. Croatian clinics provide two types of dental implants that often qualify and communicate as „Premium“ and „Low-cost“. However, even the most expensive dental implants in Croatian clinics stand out at a significantly lower price than those in Western European clinics.

A particularly attractive method of therapy „All on 4“, originally conceived by the Swiss manufacturer „Nobel Biocare“ [16], was later applied under by other names, by which partial or complete edentulousness is resolved. It is a method in which a fixed denture is mounted on

only four dental implants. If a fundamental precondition is met, such as a sufficient volume of the jawbone for implant placement, the patient can reach a final and long-term solution in a concise time. This method is still widely used today, emphasizing the short time of therapy (often in just 24 hours) and the excellent value for money. Prosthetics are most often realized with metal-ceramic and zircon-ceramic dental crowns, in Croatian clinics also significantly lower prices than those in Western European countries.

Foreign patients in Croatian dental clinics are also attracted by diagnostics accompanied by state-of-the-art diagnostic equipment, most often for 2-dimensional and 3-dimensional jaw imaging. This service is, in most cases, free of charge, which is unthinkable in Western European countries.

POTENTIALS OF FOREIGN MARKETS

Dental tourism is based on the provision of equal or more valuable dental services outside the home country at more favourable prices with added value in the form of tourist offers and arrangements. Depending on the country, these differences can become significant. For example, some private clinics in Moldova offer implant or prosthetic services to potential Italian patients far more affordable than Croatian clinics through leased Italian domains and websites as shown in Table 1 [17, 18].

Table 1. Prices of dental services in Croatia, Moldova and Italy [17, 18].

	All-on-6 (fixed full arch on 6 dental implants), €	Metal Ceramic Crown (bridge, 14 pieces), €	Zircon Ceramic Crown (bridge, 14 pieces), €	Metal Ceramic Crown on dental implant, €	Metal Ceramic Crown, €
Italy*	9 377*	–	–	1474*	615*
Croatia	6 700	4 200	2 600	800	190
Moldova	2 683	3 402	1 540	414	110

Despite not being the most favourable compared to other Eastern European countries, Croatian clinics have found ways to enter Western European markets, with still more favourable prices and quality of service. It should be noted that Croatian dentists and clinics in recent years are highly ranked in Europe, when it comes to quality, and are ranked among the best in Central and Eastern Europe [19], a group dental website that includes 27 Croatian clinics that provide dental tourism services, a comparison of dental services in the UK and Croatia shows how many Croatian services are more favourable, even when the costs of travel (arrival/return) and accommodation are included, as shown in Table 2 [20].

Table 2. Prices of dental services in UK and Croatia [20].

Dental service	Prices UK, £	Prices of Croatian dentists, £
Implants and implants placing	2 100	430
Mobile orthodontic appliance	1 500	650
Metal ceramic crown	700	150
Zircon ceramic crown	850	220
Artificial bone	500	230
Tooth extraction	110	22
Endodontic root treatment	300	70
Aesthetics fillings	220	70
Scaling and teeth polishing	65	40

In Figure 1 [21], the statistic presents the cost of dental implants in selected countries in Europe in 2016. Among those listed, the United Kingdom was the most expensive country for dental implants at 3 500 US dollars, compared to 850 US dollars in Croatia.

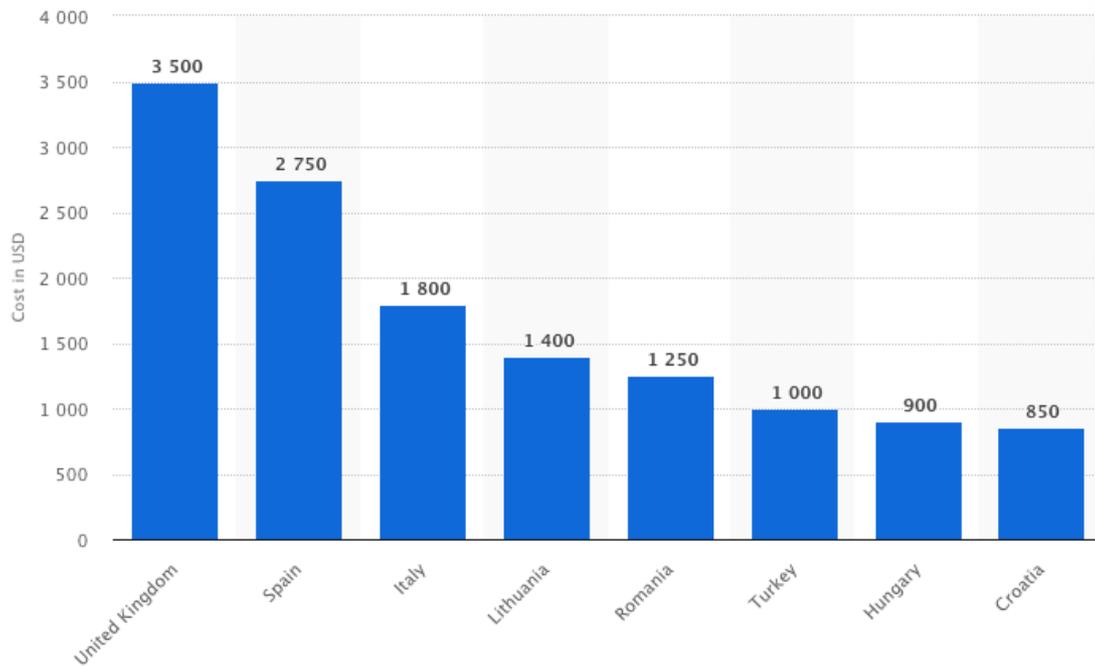


Figure 1. The price ratio of dental implants in some European countries in 2016 [21].

A study conducted at the University of Medical Technology in Rotterdam shows a comparison of the prices of individual dental services in the UK, Italy, Germany and France [22], as shown in Table 3. The prices in these countries, especially those in the United Kingdom, are significantly higher than those in Croatia. Given the above, a significant breakthrough in the UK market was made by only one Croatian clinic, „Dentum“ from Zagreb, retaining that market to this day.

Table 3. List of European countries with prices of dental services in dental tourism, from the most expensive to the cheapest [22].

Country	Price of service (dental fillings), €
UK	156
Italy	135
Germany	67
France	46

While the United Kingdom initially seemed a distant and financially unfavourable country for marketing activities, Croatian clinics turned to neighbouring countries, especially Italy. Good neighbourly relations, a long tradition of Italian tourist arrivals and good infrastructural connections seemed to be an ideal starting point for attracting new patients from Italy. Also, advertising in Italy is financially much cheaper than in the United Kingdom.

ADVERTISING OF DENTAL PRODUCTS AND SERVICES IN DENTAL TOURISM IN THE REPUBLIC OF CROATIA ON SOCIAL NETWORKS

Looking back a decade or more, it should be taken into account that advertising on social networks was far more affordable than it is today. With the possibility of targeting, the ads were precisely pointed to the desired group, in contrast to offline, i.e. print media, radio and television, which communicated widely to all groups. Advertising on social networks offers the selection of the target group according to age, gender, geographical position, interests and

other factors that much help to achieve the desired advertising results. Facebook and Google were the main channels of communication and advertising platforms, and they have maintained those positions to this day.

If we look at online advertising and the fact that the average CPC (cost-per-click) in 2005 for the whole industry was \$ 0,52, and in 2019 \$ 3,82, it is clear that advertising 15 years ago was significantly cheaper [23]. This is a direct consequence of the constant growth in the popularity of social networks. Facebook has caused the price of advertising to rise because the number of users who wanted to display ads has drastically increased.

From 100 million Facebook users in the third quarter of 2008, Facebook grew to 2,603 billion users in the first quarter of 2020, as shown in Figure 2, and Facebook is the first social network to exceed one billion users in 2012 [24]. Figure 3 shows the number of monthly users of Facebook products from the second quarter of 2018 to the first quarter of 2020 [25].

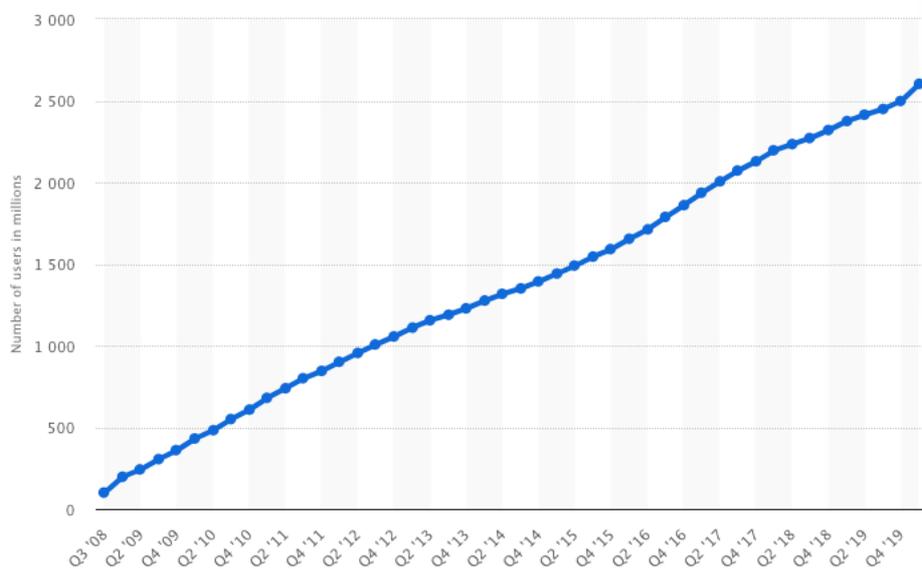


Figure 2. Number of active monthly Facebook users from the third quarter of 2008 to the first quarter of 2020 [24].

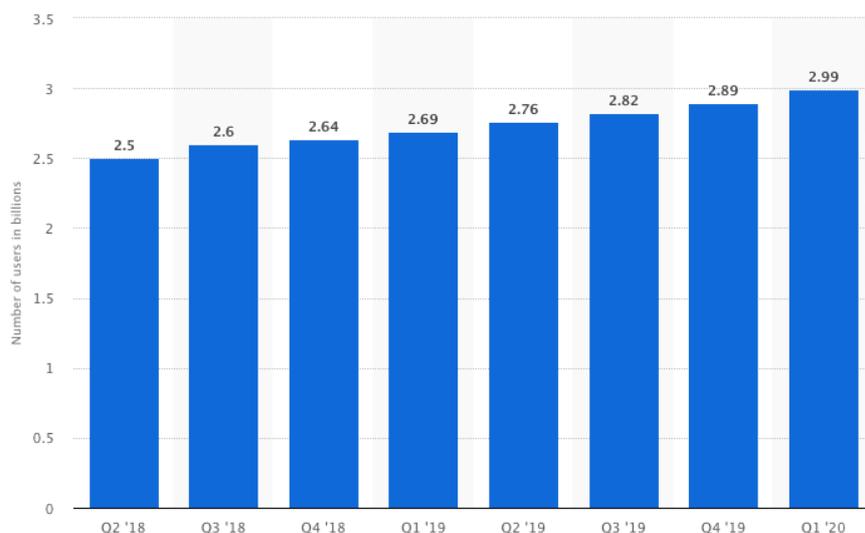


Figure 3. Number of monthly users of Facebook products from the second quarter of 2018 to the first quarter of 2020 [25].

The popularity of Facebook is especially pronounced in Italy, where for seven years it has been the leading social network in terms of the number of users, with 80,87 %, which can be seen from Figure 4 [26].

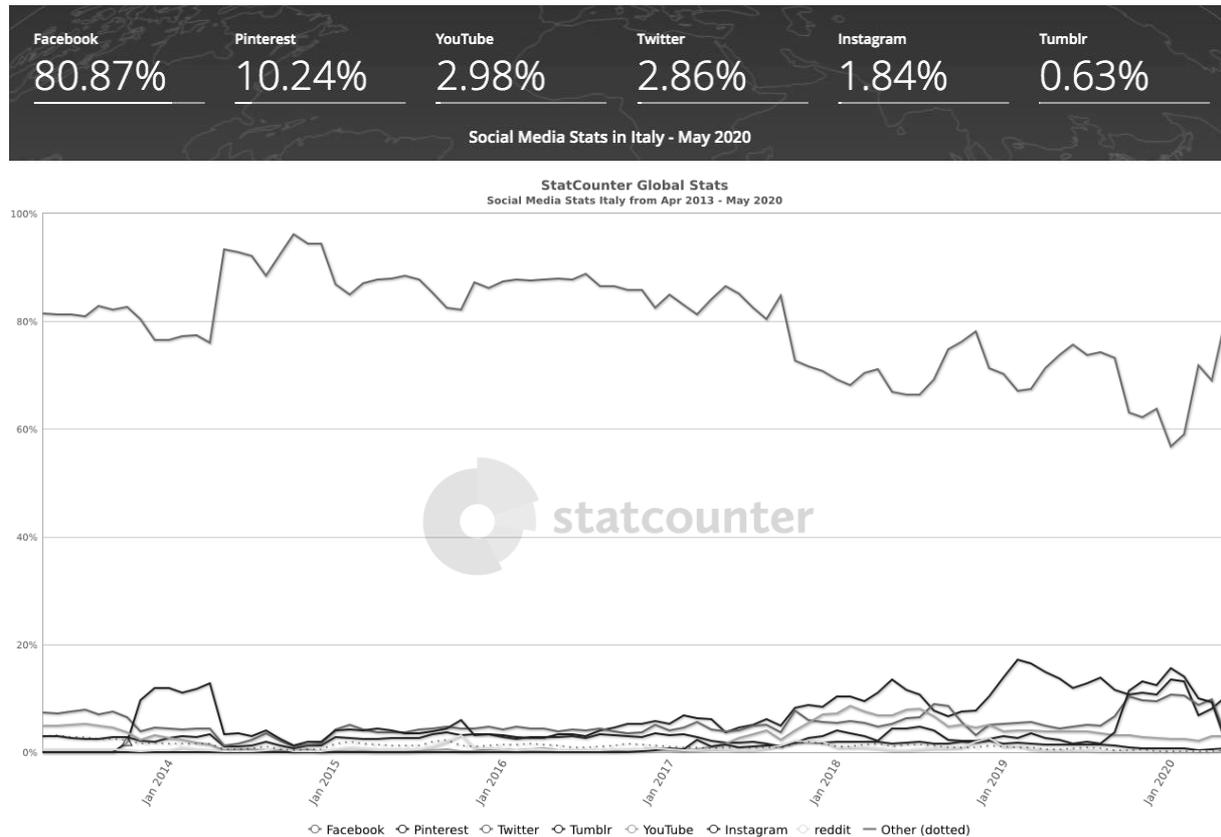


Figure 4. Percentage of Facebook users in Italy compared to other popular social networks: Pinterest, Twitter, Tumblr, YouTube, Instagram, Reddit and others in the period from April 2013 to 2020 [26].

The first Croatian clinics that realized the enormous potential of advertising on social networks in Italy, with an emphasis on Facebook, which provided cheaper and faster results of advertising campaigns than Google, were able to achieve goals unimaginable today. Thanks to the way of advertising, the target group on Facebook got acquainted with the new offer of dental services in Croatia, i.e. outside the home country. It was immediately clear to them that the solution to their problems was not far away and that it was not necessary and expensive but on the contrary. The first contacts were made, and it was not long before new patients arrived from Italy.

Another critical factor that has played one of the essential roles in attracting users to advertiser pages is the advertising rules. Namely, at that time, for the first time, even though from the very beginning of Facebook there were clearly defined Terms of Use, the system was such that it allowed advertising that is impossible to implement today. It is textual and visual content, and a combination of both, which did not necessarily refer to dentistry itself. This, in turn, meant that an attractive Facebook ad could be created that would lead the user to click, but for 'pulling in', despite the assumption that the user, once he saw what it was about, would move on. As in this form of marketing, most of it comes down to the law of large numbers, such advertising has proven to be effective because it has generated a large number of inquiries from potential patients. A step forward occurred when concrete services began to be offered at special prices and when price differences in Italy and Croatia were

communicated. However, even in such advertising, there was a delay because not all information related to the offer of services was necessarily communicated, which caused additional curiosity of users and an increased number of inquiries. This primarily refers to the manufacturers of implant prostheses and the technique of doing prosthetic works, which significantly forms the final price. Advertising was allowed to include examples before/after, which usually caused a massive reaction from users because they could identify with the dental case or problem, but also clearly convince of the final result.

In recent years, Facebook has enacted new advertising rules that make today's advertising significantly more difficult. Among other restrictions, there is a rule that explains that it is forbidden to use before/after examples in advertising: „*Personal Health: Ads must not contain „before-and-after“ images or images that contain unexpected or unlikely results. Ad content must not imply or attempt to generate negative self-perception to promote diet, weight loss, or other health-related products*“ [27]. There are many other rules, and everyone is asking advertisers to apply the advertising strategy for the clinics.

In addition to the above restrictions, it is crucial to pay attention to the text part of the ad. It is not allowed to use words that could mislead the user or create discomfort. Glorification is not permitted, nor is an idealization. Also, Facebook monitors whether the ad is linked to the website and whether the website communicates what the ad represent.

The former practice was, in addition to the main page of the clinic, splitting services into dozens of websites (landing pages), different names and web addresses. They didn't even necessarily have to communicate the same visual identity of the clinic or make a link to the parent clinic in the name of the web address (URL). Moreover, many of the URLs contained words that referred to the service or region itself, for example: all on 4, implantologia, dental implants, croazia dentisti, dentist zagabria, denti rovigno.

But looking back ten years, the most significant difference in advertising is the user reach for the same invested advertising budget. Namely, Facebook advertising is based on the estimated reach of users conditioned by the spent budget [28, 29], as shown in Figure 5 and Figure 6.

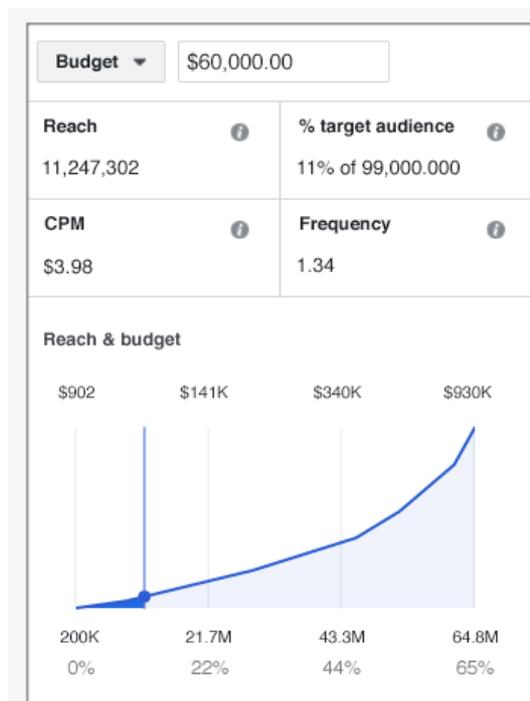


Figure 5. Example of advertising on Facebook with an estimated budget of \$ 60 000 [28].

For ad campaigns aimed at more than 200 000 people, reach and frequency buying gives advertiser predictable and controlled ad delivery at a locked price. Advertiser chooses how many people see its ads, how often and even the order in which they see them and plan out those details up to six months in advance. The advertiser also knows how far its money goes. Reach and frequency shows advertiser the exact budget it needs to reach and its intended audience. Once advertiser ads have been set up, it will deliver the ads at the booked price [28].

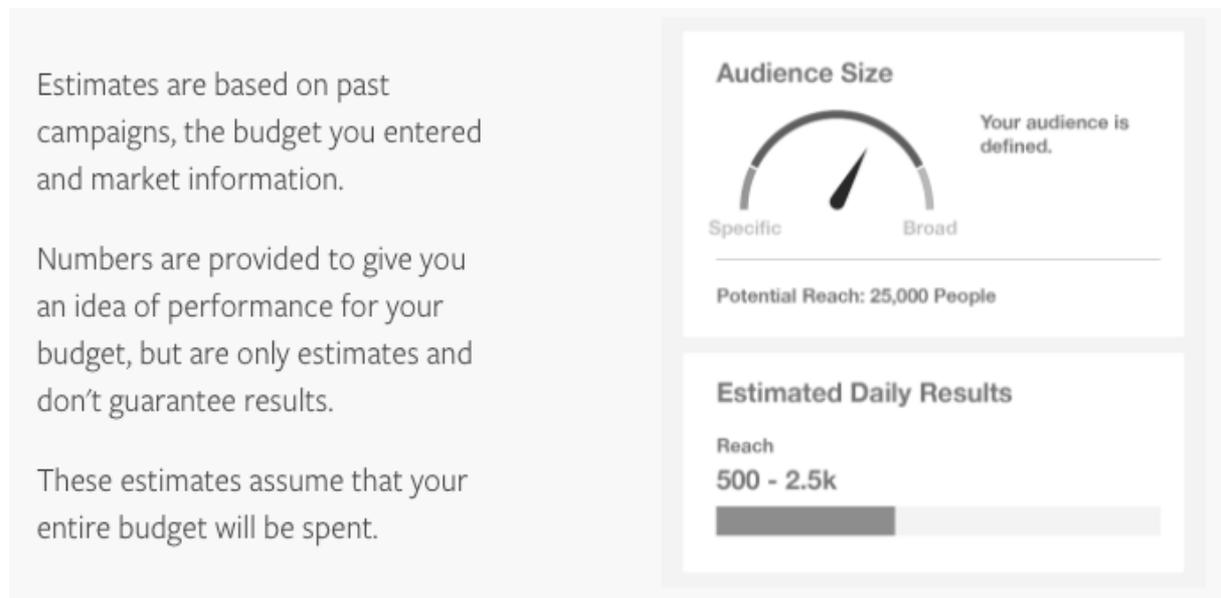


Figure 6. Estimate Audience Reach according to Facebook [29].

For ease of understanding, imagine that for \$ 100, we can reach your ad to approximately 5 000 to 10 000 users. Over time, Facebook began to reduce that reach, so that after a year or two, with the same budget, the reach was reduced to a maximum of 7 000 users, a year later to 5 000, and ultimately today's reach is only 200 to 1000 users. It is not difficult to conclude that this is a multiple price increase that today most smaller clinics can hardly keep up with, especially if it intends to advertise in a foreign market. The results of earlier advertising, compared to today's advertising, were spectacular and sufficient to launch dental tourism, i.e. for the arrival of international patients in the short term, primarily attracted by cheap and effective advertising.

THE ADDED VALUE OF DENTAL TOURISM IN THE REPUBLIC OF CROATIA

The added value of dental tourism in the Republic of Croatia was offered in the form of a free dental examination without further obligations. This meant that a foreign patient could do a complete diagnostic examination and consultation with specialists utterly free of charge and receive an initial offer for dental services. If we take into account that in most Western European countries diagnostics, examination and preparation of the offer are charged, the fact that it is given as a gift in Croatia is a sufficient reason to decide to go to Croatian clinics.

However, the benefits did not end here. Free transportation in both directions is organized, as well as hotel or apartment accommodation. In the case of Italian patients, the usual practice was to arrange with several patients who, on a specific date and at a specific time, moved in an organized manner from Italy to Croatia utilizing transport by clinics. The variations were either to connect the two cities directly, Italian and Croatian or to stop in passing cities on a given route. In addition to all of the above, patients were offered free accommodation even if they only came for an examination. The arrival of an escort, such as family members or friends, was charged. Those clinics that did not have their means of transport or more strongly

developed logistics, hired Italian or Croatian agents whose job was to collect and transport patients with a certain percentage of the commission from the provided dental services.

Thanks to social networks and the investment of clinics in advertising and communication, the word about the quality of services in Croatian clinics spread instantly, which caused even greater interest.

RAPID REVENUE GROWTH OF CROATIAN DENTAL CLINICS AS A RESULT OF INVESTMENT IN ADVERTISING AND COMMUNICATION

If we analyze the data of Fina, the leading Croatian financial agency, from 2017, as an example of a great business year, which speaks of the healthy growth of the ten largest dental clinics in Croatia, we can see a significant increase compared to the previous year, as shown in Table 4 [30, 31].

Rijeka's „Rident“ as the largest dental and, in general, the largest private health clinic in Croatia, recorded annual revenue of 16,08 million euros, or 2 % more than the previous year, with a profit of 2,86 million euros.

Zagreb's „Ars Salutaris“ in 2017 generated revenue of 3,79 million euros, which is an increase of as much as 22,5 % compared to the previous year, with a profit of 270 000 euros.

The growth of the „Implant Center Martinko“ from Zagreb is especially significant. From 2012 to 2016, revenue tripled, from 1,4 million euros to 3,79 million euros, while the profit in 2016 amounted to almost 250 000 euros, or as much as 174,23 % compared to 2015.

Zagreb's „Identalia“ also joined the most successful Croatian dental clinics, regardless of the decline in revenue compared to 2016, 28,45 million euros, with a profit of 440 000 euros.

A relatively new clinic in dealing with foreign patients, „Arena Clinic“ from Zagreb, in 2017 generated revenue of 3,78 million euros, profitable growth of as much as 51,3 % compared to the previous year and a profit of 120 000 euros.

In the company of the top ten most successful Croatian dental clinics in 2017 were „Orto-Nova“ from Rijeka, „Dental Polyclinic Dr Jelušić“ from Opatija, „Polyclinic Dubravica“ from Šibenik, „Dentvitalis“ from Rijeka and „Digital Smile Academy“ from Zagreb.

Table 4. Business operations of the ten most successful dental clinics in the Republic of Croatia in 2017 [30, 31].

Dental clinics	Revenues, 1000 €	Change 16/15, %	Profit, 1000 €	Change 16/15, %
Rident (Rijeka)	16,08	1,97	2,86	-33,10
Ars Salutaris (Zagreb)	3,79	22,52	0,27	83,58
Implant Center Martinko (Zagreb)	3,79	24,48	0,25	174,23
Identalia (Zagreb)	28,45	-19,67	0,44	-60,51
Arena (Zagreb)	3,78	51,30	1,21	17,00
Dental Studio Vukić (Zagreb)	2,78		0,69	
Orto-Nova (Rijeka)	2,32	25,95	0,14	-29,63
Dental Polyclinic Dr Jelušić (Opatija)	2,22	10,24	0,42	-0,06
Polyclinic Dubravica (Vodice)	2,17	37,76	2,14	161,81
Dentvitalis (Rijeka)	2,13	25,68	0,29	127,33

All these clinics, except for „Digital Smile Academy“ from Zagreb, base their business on Italian patients. Only a small part is occupied by Croatian patients and patients from other countries.

Some clinics, such as „Identalia“ or „Implant Center Martinko“, due to insufficient capacity, have expanded their business through franchises to other dental clinics throughout Croatia. This covered the capacity, but also enabled Italian patients to come to Croatian cities that are closest or more attractive for them to visit.

The rapid growth also required additional investment in the workforce, equipment and infrastructure. The competition of Croatian clinics has led to investment in state-of-the-art diagnostic devices and dental equipment. Many clinics have equipped themselves at the level of world clinics and stood by their side. In 2017, IMTJ, the International Medical Travel Journal, an independent international organization for the promotion of health tourism, named Rijeka's „Rident“ „The Best International Dental Clinic in 2017“ [32].

The number of employees in all sectors of clinics, from surgeries, administration, sales and logistics, also increased largely. Considerable funds have been invested in the development of call centres, often divided into two work shifts because much of the interviewing with foreign patients took place in the afternoon and evening, when patients are available. Significant efforts were made to educate staff in call centres because, in addition to knowledge of a foreign language, they had to undergo communication and sales training.

Basic, commercially available IT systems and solutions were no longer sufficient for such an expanded business, so clinics began to develop their own. In addition to their computer servers and terminals, they developed custom CRM (Customer Relationship Management) and ERP (Enterprise Resource Planning) systems to improve business. Since they are individually developed and adapted to the needs of clinics, it was often a considerable investment.

GROWTH OF PRICES OF SERVICES IN DENTAL TOURISM IN THE REPUBLIC OF CROATIA

These investments came not only from their own revenues and profits but also from various bank loans, especially when it came to the purchase of dental equipment and the purchase of real estate to expand the clinic. Inevitably, there was an increase in service prices because the previous business model proved unsustainable due to significant investments and indebtedness. Free check-ups in clinics remained in several cases, while transport and accommodation began to be charged, and it was free for patients undergoing therapy.

Since advertising on social networks began to be used by other Croatian clinics, there was a 'congestion' in the Italian market. It should be kept in mind that in Italy, in addition to Croatian clinics, Hungarian, Slovenian, Romanian, Albanian, Serbian, Bosnian, Bulgarian, Turkish, Russian, Moldavian and many others were advertised. Croatian clinics could no longer rely only on advertising on social networks, so they looked for other channels of promotion. For example, being one are specialized tourist fairs in Italy, where certain Croatian clinics presented themselves on Italian soil and thus made contact before patients came to Croatia. This way of promotion proved to be financially unsustainable for many and was accepted only by a few clinics in Croatia that is present at several tourist fairs in Italy every year. The additional promotion included paid advertisements in local, Italian newspapers, radio commercials, billboard posters and distribution of promotional materials in shopping malls. The investments were significant, all to better position themselves to attract Italian patients.

THE SENSITIVITY OF THE DENTAL TOURISM MARKET

The sensitivity of the foreign market, i.e. doing business with a foreign market, is also shown by the fact that in 2016 there was a drop in the arrival of Italian patients in the Republic of

Croatia after the terrorist attack in March 2016 in Brussels, Belgium. A collective fear of travel was created, not only among the local population but also among the inhabitants of other European cities. Terrorists target public transportation given their direct psychological impact on people's short-term motivation to travel, thus, paralyzing almost immediately an entire area or even an entire city and consequently causing severe economic damage [33].

The decline in traffic was felt in the transport and tourism industry, as well as in other sectors of the economy, and in the provision of dental services in dental tourism in the Republic of Croatia, which resulted in a drastic decline in demand and interest of Italian patients to come to Croatia. This chaotic situation was relatively short-lived, but it was very indicative and clearly showed what could happen if the influx of Italian patients to Croatian dental clinics were to stop. Even after that shorter period, additional efforts had to be made to patch up the financial gaps created by reduced revenues. This was felt by almost all dental clinics in Croatia that were working with foreign patients from all European countries at the time.

If we return to investments and the consequent rise in service prices, then it should be taken into account that in the meantime the so-called „low-cost“ private dental clinics appeared in Italy, offering more favourable prices than other Italian private dental clinics with prices almost equal to those in Croatia. This was not taken as a potential threat to the business of Croatian dental clinics since even in such low-cost Italian private dental clinics, in addition to the primary service, everything else is charged: diagnostics, examination, counselling, offerings, raw materials, even anaesthesia. . Ultimately, Croatian prices were more favourable, and it was considered that dental work in Croatia was of better quality.

The Italian market, and any other foreign market, could not be observed only through prices, without taking into account the mentality and habits of the people. Italians like to travel, they are not foreign to consumption outside their home country, but the prices of services are essential to them. If they think that, for example, in Hungary, they will get a cheaper and equally high-quality dental service, the extra kilometres will not be a problem for them. And that is exactly what happened. Croatian dental clinics, due to all above mentioned, had to raise prices, and then the interest of Italian patients dropped significantly. In a clinical system that employs 100 or more people, a drop of 20 % or more means 10 to 20 more people in the collective. The decrease in turnover did not stop financial investments and liabilities to banks, so clinics sought salvation in loan rescheduling and cash injections. Now clinics have become patients who need help. Some salvation was seen in foreign and domestic investment funds. Many of them offered to take over the clinics, but at a significantly lower price than the real one. The funds found justification for the low supply in the fact that the clinics are business-oriented to one foreign market, which poses an investment risk.

CONSEQUENCES OF THE COVID-19 PANDEMIC ON THE WORK OF DENTAL CLINICS IN THE REPUBLIC OF CROATIA

And while some clinics were already ready for such an unfavourable takeover, the worst happened, European borders were closed due to the COVID-19 pandemic caused by the new SARS-CoV-2 virus. After China, South Korea and Iran, Italy proved to be the first European outbreak of the disease with devastating consequences and heavy casualties, as shown in Figure 7 [34].

All arrivals of Italian patients in Croatia were cancelled, although many appointments were arranged several months in advance. The biggest problem at the time was that no one knew how long the interruption of the arrival of Italian patients would last, or how long the pandemic would last. At that time, it was quite clear that business with foreign nationals would be suspended for at least a few months, which in the case of Croatian dental clinics, whose business is based mainly on Italian patients, met the danger of complete collapse.

In Italy, from Jan 29 to 8:18am CEST, 27 June 2020, there have been 239,706 confirmed cases of COVID-19 with 34,678 deaths.

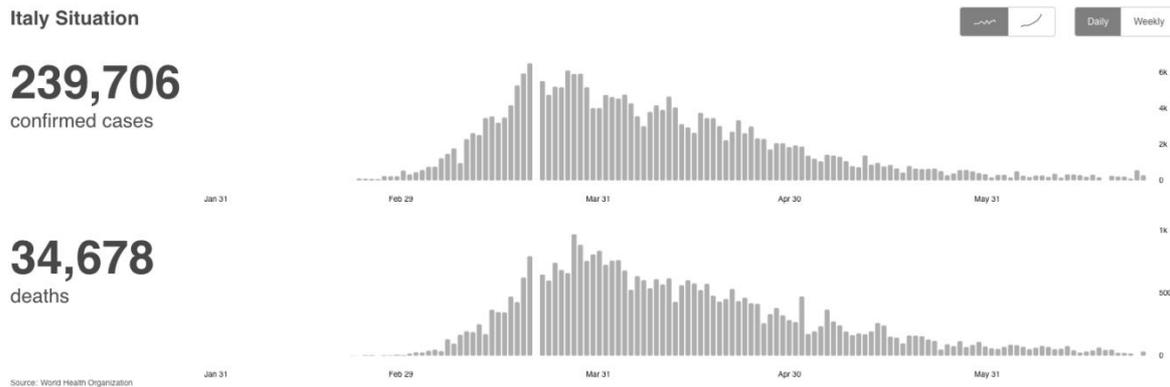


Figure 7. Number of patients in Italy from Coronavirus disease (COVID-19) from January 29, 2020 to June 27, 2020 [34].

As dental tourism in Croatia also relies on citizens of other European countries, the arrival of patients from Germany, Austria, Slovenia, United Kingdom, France, Belgium, Sweden and overseas countries such as Canada and the United States has been suspended.

Soon followed the recommendation of the Ministry of Health of the Republic of Croatia [35] and other professional organizations, the Croatian Medical Association [36] and the Croatian Society for Oral Surgery [37], to suspend work with Croatian patients and to accept only emergencies. Even emergencies were approached with special caution because there was a possibility of infecting doctors and assistants with the SARS-Cov-2 virus. Although dentists have experience working with patients with HIV or hepatitis, and approach such patients with increased precautions and protection, in an epidemiological situation where the virus is unknown, and there is no cure, the fear and decision to receive and handles only a minimal number of emergencies was justified. Due to the situation, many dental clinics and surgeries have completely stopped working.

In a short period time, the revenues of dental clinics in the Republic of Croatia were reduced to zero, which led to a reduction in the number of employees, i.e. to sending employees on unpaid annual leave. This primarily included employees involved in the logistics part of the business: drivers, administrators, call centre employees, staff to welcome and monitor the movement of patients, maids, janitors and other employees actively involved in dental tourism. Furthermore, business contracts for the rental of hotel and apartment accommodation were terminated, as well as deals with travel agencies and agents in charge of bringing patients from European countries.

At the time of the suspended and drastically reduced revenues, there were still credit obligations to banks that financed the expansion of operations by purchasing new dental equipment, raw materials, movables and real estate. The package of measures adopted by the Government of the Republic of Croatia at the session held on March 17, 2020, which postpone the obligation to pay certain taxes and contributions to dentists involved in dental tourism was not helpful because these measures covered three months with the possibility of extension for another three months and subsequent instalment payment of the debt for 24 months [38]. As it was already probable at that time that there would be no patients from abroad in the Republic of Croatia for at least three months, such measures could not be an aid in the crisis. Only the subsequently adopted decision of the Government of the Republic of Croatia on a new package of measures on co-financing contributions and minimum wages somewhat mitigated the situation and reduced the number of dismissals [39].

STEPS FOR OVERCOMING THE CRISIS OF DENTAL CLINICS IN THE REPUBLIC OF CROATIA

Expansion of business to more countries abroad and more intensive business with Croatian patients

Exit from the crisis must include restructuring the operations of dental clinics, especially in the segment of dental tourism. Even if the COVID-19 pandemic had not happened, clinics needed to turn to a different business model. This primarily involves expanding to more overseas markets resulting in better resilience of dental clinics. Besides, clinics that base their operations on foreign patients incoming must not neglect Croatian patients, regardless of their lower economic power compared to that of patients from Western European countries. It is impossible to successfully develop dental tourism in the long run without focusing on the domestic, Croatian market. However, the trust of Croatian patients has been building for years, and it is impossible to gain it in a short time and out of necessity.

At a time when the borders were closed and when the work of dental clinics with Croatian patients was not yet prevented, some dental clinics decided to drastically reduce the prices of services to attract Croatian patients. Such a business move, i.e. advertising cheap services, met with great dissatisfaction from other clinics and dental practices, so the Croatian Dental Chamber (CDC) reacted with an official statement in which, among other things, it was pointed out the unethicallity of advertising and highlighting unethical discounts aimed at had, in addition to competition rules, attracting patients to surgeries or clinics without providing them with complete information on protocols and hidden treatment costs. In case of identified unethical discounts that could not ensure adequate provision of health services in terms of care for patients' rights and protection and provision of professional protocols and technical conditions as well as appropriate long-term monitoring and prevention of possible complications, the Chamber took measures within its competence to the entities that provided such services, but also to members of the Chamber who knowingly participated in the provision of these services [40].

Drastic price reductions are not only an unethical procedure but also create mistrust in many potential patients. They can rightly ask how the interest in domestic, Croatian patients suddenly arose and why they are offered such discounts, mainly because the services of these clinics were out of reach precisely because of the high prices.

An additional problem is the poorly developed communication strategy of some clinics in crises. In the pandemic, many outpatient clinics also cut off communication with current and future patients. The reason for stopping advertising on foreign markets on social networks and all other platforms in the context of the promotion and offer of dental services or attracting the tourist potential of Croatia is justified. However, in many cases, any communication was interrupted, and all marketing activities were put on hold. This proved to be wrong because those dental clinics that reduced the volume of marketing activities but maintained contact with patients, at the time of easing the measures more easily resumed business.

One section of dental clinics has reduced communication with patients to informative content that communicated advices on what to do if dental problems arise during the epidemic, and the clinics are closed. Here, Facebook has proven to be an excellent platform for online consultations, direct contact of clinic owners to patients, collection of information on dental status, arrival planning and post-epidemic therapies. Such a strategy gave patients the feeling that they were not alone with their problems and that they could count on help. It should be noted that at the time of closing the borders, many foreign patients were in the initial stages of therapy and had made advance payments. It is quite clear that these patients were the first to

ask for additional information about the continuation of treatment and how to behave to preserve oral health in the new crisis.

Reducing capacity and focusing on individual services

It is very sure that after the COVID-19 pandemic, the spread of dental clinics will be drastically stopped, especially since the pandemic is still going on. Reducing the capacity of large clinics is already proving to be the right solution. A clinical system of a dozen or more surgeries, a hundred employees and a vast infrastructure will be almost impossible to maintain within a positive financial framework. The trust of foreign patients is seriously undermined by fear and economic uncertainty. It will take a long time for patients to decide to come to Croatian clinics again, which means reduced income. Also, in the process of restructuring, it is inevitable to reduce the number of employees, i.e. to dismiss them.

On the other hand, dental clinics will need to put emphasis on individual services and make an extra effort to show why they are the best in those areas. When it comes to implantology, then clinics must give the maximum to explain to potential patients precisely why implantology is applied and what its benefits are. They need to communicate clearly who is installing the dental implants and with what experience. Showing complete cases through photographs, video and textual descriptions to illustrate how the problem can be successfully solved, will create interest, but more importantly – trust. Clinics need to know that patients primarily want to solve their problem, and it is up to clinics to show how they do it successfully and on what number of patients. A narrower focus on individual services will help the profiling of clinics, and patients to more easily create an image of whether they are in the right place, but also to ultimately accept the price of the service. This will make it easier for clinics as well, because for these reasons they will focus on certain specialists and the purchase of equipment, and the restructuring must include external associates, agencies and companies to reduce business risk. Service prices will continue to be the main reason of interest for foreign patients, but not the only one. Now is the right time for clinics to start developing dental tourism in the full sense and that dental tourism does not only mean transportation, accommodation, services and possible sightseeing during their stay in Croatia but a much broader context.

Dental tourism helps long-term attachment of the patient to the clinic even when he no longer needs dental services. Positive experiences will be transmitted orally, and a recommendation will be created that under normal circumstances cannot be paid for with money. Clinics need to communicate with patients and remind them of their presence continually. Tourist offers must become part of the added value of dental services and must include various arrangements throughout the year and be offered to patients and their families and friends.

Continuation of marketing activities

Although in trouble due to the new situation, dental clinics in Croatia must continue to invest in marketing. Facebook and Google will continue to be the leading platforms for advertising, but following the offer of the service and the target group, all other digital platforms on which advertising is enabled should be taken into account. Clinics must develop their systems for monitoring marketing activities or seek the help of specialized agencies. Today, when the price of advertising on digital platforms is high, and with a tendency to grow, it is vital to know which channels to direct the budget too.

Some larger clinics within their organization have developed their marketing team, which has its pros and cons. It is good that the received information can be processed faster, but it is bad

that this information is most often viewed from the perspective of the dental clinic itself and focused on a specific market, without taking into account global trends.

Future marketing activities of Croatian dental clinics must include clearer communication related to individual services and prices. Clinics must be aware that a potential patient, i.e. a user of a digital platform, today no longer feels responsible for having to react to the initial offer after clicking on the ad and asking a question. This is due to oversaturated advertising when clinics offer the same services at comparable prices. The user now knows that he can choose and that he will seek help when he wants to, not when the ad suggests it. Communication skills are essential in the sales segment, and clinics should focus on recruiting and educating sales staff.

Education must be passed on to both current and future patients. For example, pointing out the consequences of delaying the resolution of dental problems or prevention is no longer enough to communicate only through blog posts or Facebook posts. It is crucial to deal with the problem and use all possible communication tools to explain the treatment procedure better, the final result and the benefits of dental tourism. Depending on how well the clinic will be able to assess the need to go beyond standard advertising frameworks and be willing to explore other platforms and connect with other organizations that can help develop dental tourism, so much can expect long-term positive results. Of course, research of other foreign markets must also be included.

CONCLUSION

The current situation caused by the COVID-19 pandemic does not inspire too much optimism. Although the borders with neighbouring countries have opened, clinics are currently working with international patients who come to complete the started therapies. When and if international patients will ever return in the pre-pandemic range, at this moment is impossible to predict. Therefore, the business strategy of clinics in dental tourism must change drastically. Croatia has a huge tourist potential, and clinics must know how to use it. Informing potential patients is crucial. One should be aware of the fact that many Croatian neighbours still do not know which are the larger cities in Croatia and where they are geographically, nor what awaits them when they cross the border and go to an unknown clinic for a dental procedure.

To achieve continuous quality development of dental tourism in the Republic of Croatia, but also in general, it is necessary:

- understand the functioning of dental tourism,
- have realistic expectations related to the realization of set goals,
- develop appropriate branding,
- have adequate logistics, and
- continuously improve, and nurture, communication.

Dental tourism is not just attracting foreign patients and providing services, but it also brings additional values that, in addition to the basic service, complete the offer of dental tourism. Dental tourism represents the long-term achievement of goals, long-lasting connections with patients and relationships that include, in addition to doctors or dentists, many key people inside and outside the organization as well as strategic partners. In this chain, each stakeholder has their responsibility, and umbrella management is essential, and necessary because otherwise the development of dental tourism can be wasted with negative business results.

In the development of dental tourism, it is essential to set goals according to the current capacity of the practice, i.e. the possibilities of appropriate quality treatment of the optimal number of patients on a weekly and monthly basis, and a solid strategic plan, otherwise wrong business moves can occur with poor long-term results.

Developed branding is crucial. Placing a service on a foreign market without an established own brand is a painstaking and challenging journey. What seems at the moment to be recognizable on the Croatian field and which may be enough for regular business is not enough for placement on a foreign market and increase in income. A recognizable brand is created by precise planning, investment and involvement of strategic partners. Accepting the fact that in an international market your brand is a big unknown can help you see the bigger picture and make the right business decisions and moves. Besides, if we start from the fact that branding takes place in the minds of patients and is not tangible, the preconditions are created for the quality development of a quality brand and, in general, dental tourism.

The development of adequate, appropriate, quality logistics is significant. Several elements will prove to be crucial for the development of dental tourism, and the basic ones are marketing activities, educated staff, sales centre and infrastructure available to the organization. The expertise of doctors and assistants, as well as premium services and equipment, are taken for granted. Before targeting a particular foreign market, one should ask who within the organization can follow that market in terms of knowledge of the language, habits, trends, and economic and social circumstances of the target country. Reducing responsibility to some people in the development of dental tourism leads to serial communication and complicated business with a negative effect.

Appropriate, comprehensive (complete), quality communication is of great importance for the quality development of dental tourism. The first contact with the patient begins with the expressed interest of the patient for the services of practice or clinic. Often this interest is lost if sufficient communication is not provided in terms of obtaining all relevant information. Then the excuse for failure is attributed to the inappropriate price, that is, the fact that the competition may offer a more favourable service. However, in reality, the patient is, in fact, not sufficiently familiar with the offer of the dental clinic and is not fully informed of what he gets for his money. Furthermore, communication takes place not only verbally, where the sales centre directly explains the offer by calling, but also through other communication channels such as social networks, newsletters or video channels. It is essential to understand that the fact that, for example, an inquiry came from a website does not mean that the potential patient is fully aware of the service and its value. Communication on several levels and platforms is perhaps the most critical part for the successful development of dental tourism, and it has often been shown in practice that the dental clinic that masters communication skills have a significant advantage over the competition.

When it comes to quality, Croatian dentists and Croatian dental clinics have been highly ranked in Europe in recent years and are ranked among the best in Central and Eastern Europe. This is an additional confirmation that in addition to the tourist potential and the quality of the offer and services, sufficient predispositions have been created for the continued development of dental tourism in the Republic of Croatia, even better and more accessible to a wider circle of patients from around the world.

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MITIGATING THE IMPACT OF COVID-19 IN CONFLICT ZONES

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DOI: 10.7906/indecs.18.4.4
Brief Report

Received: 9 June 2020.
Accepted: 5 August 2020.

ABSTRACT

The COVID-19 pandemic has affected the whole world. The conventional narrative has focused on developed nations. However, developing nations and conflict zones have also been disproportionately affected. In this article, I want to bring attention to the effect of COVID-19 on conflict zones. I outline the key challenges and some remedial measures which can be taken.

Leaders of the world and international organisations like the WHO and the UN need to act rapidly to prevent greater loss of life in the world's conflict zones. Peacekeepers, healthcare workers, aid organisations and local bodies need to work together to ensure that the effects of COVID-19 in conflict zones are mitigated.

KEY WORDS

COVID-19, conflict zones, developing nations

CLASSIFICATION

JEL: D74, I12

INTRODUCTION

The COVID-19 pandemic has affected the whole world. The conventional narrative has focused on developed nations. However developing nations and conflict zones have also been disproportionately affected. In this article, I want to bring attention to the effect of COVID-19 on conflict zones.

A recent article has highlighted the plight of refugees and migrants during the current COVID-19 crisis [1]. Another recent study has looked at the effect of social isolation measures in containing the COVID-19 outbreak in China [2]. The efforts of the authors are to be lauded. As developed nations are tackling COVID-19 aggressively, developing nations and conflict hotspots should also receive attention [3]. Social isolation measures now need to be urgently implemented in conflict zones like in Africa and in the Middle East.

However there are considerable challenges that need to be overcome if social distancing measures are to be effective in impoverished nations that are also in conflict zones. I outline a few of these challenges below:

1. There is a need for peacekeepers, aid workers and healthcare workers to have continued access to conflict zones. However this needs to be balanced with the unfortunate reality that they can also inadvertently spread the disease. Migration of peacekeepers, aid-workers and healthcare workers in conflict zones needs to be managed. A large influx of aid workers, some of whom may already be infected with COVID-19, may result in further spread of the disease. Aid workers need to take adequate precautions while attending to people in conflict zones.
2. Public transport are usually overcrowded and in many developing nations this is the only mode of transport for a livelihood. Developing economies, especially those ravaged by conflict, can collapse under social isolation.
3. Managing migration of refugees fleeing from conflict zones. As developed nations go into border shutdown, they should try to provide assistance to refugees fleeing conflict zones. This can be in the form of providing medical care in camps that also implement some form of social isolation.
4. Trust deficit in doctors and healthcare workers. Doctors were attacked during the Ebola crisis highlighting a trust deficit [4]. Many lessons have been learnt from the Ebola crisis in Africa. Community engagement has been a very effective measure in the fight against the Ebola virus epidemic in Africa [5]. Healthcare workers will need to reach out to communities and build trust in order to effectively combat COVID-19.
5. Existing diseases and epidemics. The Democratic Republic of Congo and other regions in Africa have been ravaged by a deadly measles epidemic [4, 6]. This highlights the need to also manage existing epidemics as scarce resources will be diverted to combat COVID-19 [6, 7].

Conflict zones cause armies to come into close contact with each other and cause displacement of people. They can also cause breakdowns in public health infrastructures and overcrowding and unsanitary conditions in refugee camps. All of these factors can lead to further spread of infectious diseases [8].

In places like Syria, where the civil war has raged for many years, living conditions in refugee camps can enable faster spread of the virus. It can be very difficult to implement social distancing and isolation in refugee camps where thousands of displaced people have the barest of essentials. If possible, temporary ceasefires should be negotiated by peacekeeping organisations in conflict zones.

Such simple and low-cost physical measures as face masks can also be effective [9] (in combination with social distancing and other measures to improve hygiene). Adequate quantities of personal protective equipment should be provided to people living in conflict zones and those working in peacekeeping and aid organisations.

Travel restrictions to and from countries in conflict zones (except for citizens of that country and essential personnel like people in healthcare professions, peacekeeping organisations and aid organisations) may also be helpful. These measures, although draconian, may be helpful since social distancing may be difficult to implement in conflict zones.

Authoritarian governments in these conflict zones may also impede the rapid response and dissemination of public health information that is necessary in epidemics [10]. Timely and accurate information dissemination to people living in conflict zones is critical.

As developed nations tackle the spread of COVID-19, the leaders of the world and international organisations like the WHO and the UN need to act rapidly to prevent greater loss of life in the world's conflict zones. Peacekeepers, healthcare workers, aid organisations and local bodies need to work together to ensure that the effects of COVID-19 in conflict zones are mitigated.

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INNOVATIVE STRATEGIES FOR CREATING AND ASSESSING RESEARCH QUALITY AND SOCIETAL IMPACT IN SOCIAL SCIENCES AND HUMANITIES

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DOI: 0.7906/indecs.18.4.5
 Regular article

Received: 19 February 2020.
Accepted: 3 June 2020.

ABSTRACT

Contemporary academic evaluation regimes, aiming to quantify and rank research quality, scholars and institutions, mostly rely on criteria such as metrics and citation scores. However, researchers started questioning recently whether these are the most appropriate instruments to evaluate academic excellence, especially in social sciences and humanities. Predominant evaluation criteria, such as peer review and citation index reflect only a limited scope of the research quality and relevance, as many dimensions cannot be seized through these traditional indicators, such as societal impact. In response to this criticism, a number of innovative research quality evaluation methods emerged in recent years, aiming to better reflect the complexity of often transdisciplinary research in social sciences and humanities. In this article, we attempt to review some of the most innovative strategies for assessing research quality, especially concerning transdisciplinary research in social sciences and humanities, as well as the societal impact and ‘productive interactions’. We conclude that while other innovative strategies are still in the pioneer phase, requiring more research and practical implementation, measuring societal impact emerged as a reliable, relevant, comprehensive and applicable strategy for evaluating research quality in social sciences and humanities.

KEYWORDS

research evaluation, research quality, evaluative inquiry, societal impact

CLASSIFICATION

JEL: I2

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INTRODUCTION

Modern scholarship has long been debating about the importance of research evaluation for ensuring scientific rigor, significance, and impact in both natural and social sciences. Furthermore, in the era of globalization, determining standards and criteria for evaluating research became one of the major preoccupations of not only the academic community but also that of ministries, scientific committees, nonprofit agencies, foundations and other stakeholders engaged in the research investment cycle.

Quantification, standardization, and hierarchization of knowledge production became one of the major pillars of the academic work, affecting the organization and orientation of the whole sector. As in any other branch, competition in academia created the necessity to develop indicators for assessing, evaluating and ranking research work, academics, departments, projects and institutions. Thus, sets of criteria, standards and evaluation methods have been established in order to measure performance in academic work. The most important ones, traditionally, have been the prestige of the publication venue, namely the journal-level measures such as the impact factor and the metrics such as citation index. This enabled the academic community to distinguish clearly between good and bad research work, to establish merit-based practices and shape review, promotion, and tenure (RPT) processes within the institutions.

However, in the process, academics started complaining that surveillance, evaluation, and ranking became so oppressive and demanding that the pressure to publish in a particular way and venue started hindering academic production, its quality and pertinence [1, 2]. Due to this criticism, in recent years scholars started advocating for setting the new innovative criteria for evaluating research, such as the research impact and influence in society, which became one of the most elaborated topics in the social science research agenda [3-7]. Nowadays, the evaluation of the research quality relies as much on the different kinds of impacts that are discussed in 'impact' literature, such as popularization [8, 9], business engagement [10], scientists' response to policy [11], teaching and collaborations [12, 13], influence on politics [14].

The goal of this article is to review the following topics relevant to the evaluation methods of research quality in the social sciences and humanities. First, we discuss the evaluation of the research quality in general. Second, we discuss the notion of assessing the quality of interdisciplinary research. Third, we question the usage of evaluative inquiry, as the new concept for assessing the quality of scientific research. Finally, we consider the relevance of societal impact as the measurement of research quality in the social sciences and humanities.

EVALUATION OF RESEARCH QUALITY

Traditionally, most of the research evaluation relied on measures of academic output, such as peer review and bibliometric, as tools for assessing research quality and its scientific merit [15, 16]. Thus, one of the major criteria for evaluating research quality is considered to be very the prestige of the journal in which the publication appeared (impact factor, etc.) and the number of subsequent citations in other scholarly works [17]. Although heavily criticized, journal reputation has been used as a measurable and reliable tool for judging research results in social sciences and humanities for years, even in transdisciplinary fields. But this excludes from the competition number of other publication formats common in social sciences – such as books, book chapters, conference papers, reports, reviews, etc. Citation count is also highly flawed, or to say at least, exclusionary – as most of the social science articles indexed by Web of Science are in English [18], meaning that publications in national languages, regardless of their genuine quality, remain most of the time under the radar.

These evaluation procedures have been heavily criticized lately, especially when it comes to evaluating research in humanities and social sciences, as they seem not to be fully compatible with research and scientific communication practices employed in these fields [19, 20]. In one of his essays on the topic, Wouters argues that the discrepancy between how evaluators and researchers perceive quality in research creates the ‘evaluation gap’, where scholars argue that the established assessment criteria do not coincide with what they value in their research work [21]. Especially in social sciences and humanities, scholars have been criticizing evaluation indicators and metrics as ‘unlikely to fully reflect the quality of their work’ [22]. Indeed, while citations, peer review and impact factor remain relevant for evaluating social sciences, it has been noted that additional criteria should be established to address variety of innovative approaches, actors, research designs and mechanisms, as well as the societal impact of social sciences and humanities, especially when it comes to transdisciplinary research [22].

The major issue with the dominant evaluation techniques is that they encourage researchers to focus on publishing “safe papers” in major journals, rather than to try and conceptualize ground-breaking alternative research which might not fit into the framework of mainstream journals [23]. Furthermore, the “one-size-fits-all” evaluation tools might not be appropriate for innovative research designs and alternative research concepts and methods. Different criteria and factors affect the quality of research, and it is difficult to compare research quality across the fields. What might be considered bad research in one field, could be easily recognized as high quality research in the other. Similarly, research quality depends on the context, time and place of publication – what might be highly relevant for certain communities, in a particular moment, is often unacknowledged in other settings or a different period.

ASSESSING QUALITY OF TRANSDISCIPLINARY RESEARCH

As pointed out by Belcher and colleagues, in every activity, we need sets of principles, comparison criteria or benchmarks, which should help us, evaluate its quality, potential, progress, and success [24]. It is necessary to provide reliable quality criteria in order not only to improve scientific rigor, research design and methodological tools but also to inform funders about the outcomes of their support and funding in terms of research success. The research quality is determined using mostly two main criteria – scientific excellence and scientific relevance [24]. In most disciplines, there is an established set of measures and criteria evaluating the quality of research design, soundness of methodology, originality of results. These processes are much more challenging when it comes to transdisciplinary research in social sciences and humanities since up to this day there has been no consensus or widely accepted principles and criteria for evaluating transdisciplinary work.

The majority of authors reflecting on the quality evaluation in social science transdisciplinary research emphasize the need for expansion of existing and adoption of new evaluation criteria for these research articles and projects [25]. These criteria should be made explicit and widely agreed upon, but only a few of the reviewed articles suggested the specific criteria to be used. Furthermore, it has been argued that the quality assessment of transdisciplinary research articles should be conducted by the reviewers from beyond discipline, or at least reviewers from various disciplines [26-28]. This is particularly important as researchers doing transdisciplinary research struggle with selecting publishing outlets and are often inclined to first choose a journal, and then tailor their research methods and design to “fit” disciplinary scope of the journal. This limits the advances in knowledge and the creation of innovative transdisciplinary methods.

Concerning the quality criteria for evaluating transdisciplinary research, Boaz and Ashby distinguish four criteria – methodological quality, quality of reporting, appropriateness of methods and relevance to policy and practice [29]. Spaapen, Dijstelbloem, and Wamelink

suggest that the evaluation of each research project should be conducted against its own goals and not rely on a comparison between projects [30]. According to Jahn and Keil, quality criteria for evaluation of transdisciplinary research are quality of the research problems, quality of the research process, and quality of the research results [31]. Other important criteria mentioned in the literature are stakeholder engagement, integration of epistemologies, impact agenda, diversity of result outputs, etc.

The evaluative inquiry is one of the newest concepts in the field, aiming to challenge previous instruments and organization of the research evaluation, in terms of its understanding of academic achievement, impact and the ways it should be measured. The evaluative inquiry has been first introduced by Fochler and de Rijcke, arguing that the research quality cannot be understood as a straightforward and universal concept and thus there cannot be a one-size-fits-all instrument for measuring it [1]. Instead, they suggest to reflect on the academic work as a process and understand quality as a result of the interactions between values and networks of people, outputs and resources through which knowledge is generated [32].

The main idea of this approach is that academic achievement is distributed amongst both academic and non-academic participants and thus needs to be studied through a portfolio approach, namely the multiplication of methods offering various insights into academic work and its quality. In reference to impact, this method problematizes the request to produce both high-quality academic publications and the societal relevance through it. It criticizes the idea of passive stakeholders receiving benefits from academic expertise (impact), emphasizing instead the concept of ‘productive interactions’ [15] between stakeholders. In practice, this means that stakeholders are not only co-producers of knowledge and impact, but also of the criteria by which such impact is to be evaluated [32].

SOCIAL IMPACT

As previously elaborated, most of the quality evaluation in social sciences previously relied on scientific impact [15]. The idea, which in general appears in the literature, related to impact creation and evaluation is the concept of productive interactions. In their influential study, Spaapen and Van Drooge provided a new way to think about the ways in which research creates impacts which they termed ‘productive interactions’ and defined as ‘exchanges between researchers and stakeholders in which knowledge is produced and valued that is both scientifically robust and socially relevant. These exchanges are mediated through various ‘tracks’, for instance, a research publication, an exhibition, a design, people or financial support’ [15]. This concept highlighted the importance of stakeholder collaboration in the research design, publication, and implementation, arguing that rather than some unattainable goal, societal impact in social sciences and humanities can be easily achieved by simply enhancing productive discussions between academics and policy makers.

According to Muhonen, Benneworth and Olmos-Penuela, impact creation in social sciences and humanities cases can be achieved through different forms of scientific and popular publishing, but also extensive media and public engagement, stakeholder interaction, commercialization or policy, legislation and epistemic training [7]. In their research, they develop the pipeline model detailing 12 major impact pathways, which are the interactive dissemination model, the collaboration model, the public engagement model, the expertise model, the mobility model, the ‘anticipating adversaries’ model, the ‘seize the day’ model, the social innovation model, the commercialization model, the research engagement model, the knowledge ‘creeps’ into society model and the building ‘new epistemic communities’ model. This framework might be very useful for conceptualizing different impact pathways.

Reale and colleagues distinguish between three major impact categories – scientific, social and political impact [33]. According to their findings, scientific impact in SSH could be understood as a scientific change produced by a certain piece of research, such as the transformation of the research process. The political impact is defined as the transferability of research results into the political sphere aiming to contribute to the policymaking, while social impact refers to the research contribution to social challenges by inspiring social activism or civil society interventions. For all the impact categories, the authors highlight the tendency of a participatory approach, by including new stakeholders and engaging in public debates between academics and policymakers, civil society, etc.

The impact is often addressed as the usefulness of the research and it is determined by its purpose. Thus, researchers are increasingly encouraged to undertake the research commissioned by the government, local authorities or companies, which makes research even before its creation starts highly impactful. This type of research is thus designed to answer specific societal needs or challenges. It is often conducted in close cooperation with other stakeholders and includes perspectives of several co-creators, which often makes it more relevant and applicable. Furthermore, the results of these research projects are in general widely disseminated – published in newspapers, advertised in media, etc.

However, it may be argued that due to the lack of clarity in the way policy absorbs research, and sometimes very long delays between research and impact production, it is difficult to evaluate research impact and relevance. Thus, one might raise the question of the fluidity of impact, as certain topics, which seemed not to be highly impactful at some point turned to be extremely relevant some years later. Similarly, some of the research designed to answer certain problems in society by the time it is finished can be irrelevant if another solution arises in the meantime.

The growing awareness of the importance of the social impact of research instigated the emergence of the Social Impact Open Repository (SIOR), launched by the European Commission in 2015, aiming to disseminate different social impact stories in order to inspire and encourage future impactful research [34]. It cites evidence of both real social impact, where research already created certain societal change, and potential impact, where the research results have not yet been completely translated into societal improvements, but there are some indicators that it will create societal improvements [35]. This open repository became 2015 a reliable tool for evaluating the social benefits of research and communicating different impact pathways in social sciences and humanities.

Pulido and colleagues analyzed channels of dissemination of research impact, focusing on social impact coverage ratio (SICOR) in order to identify the percentage of tweets and Facebook posts related to impact in the total number of social media data on a particular research project [35]. As social media has increasingly become the tool for academics to boost the visibility of their research, some of the communication on these platforms, as their results demonstrated, refers to the social impact of research. While their research has been limited in scope (only 10 projects were analysed), it showed that there is some, but not much of the social impact evidence in social media. Thus, this tool should be further exploited in years to come and scholars should seriously consider publishing concrete qualitative or quantitative evidence of their real or potential research impact.

A similar methodology was introduced by Cabre-Olive and colleagues, who suggested using social media as a tool for understanding emerging topics in the society in order to define research, which may create significant social improvements [36]. Another important contribution in the field was made by Gomez, Puigvert and Flecha who apply principles of critical communicative methodology to research in order to advocate for more stakeholder engagement and shared creation of knowledge (and thus also the impact) [37]. It highlights

the importance of dialogue between researchers and social actors in order to use the community's cultural intelligence in designing and conducting research. These interactions ensure not only that the research responds to the challenges important for the society, but also that the community in question better accepts and more quickly implements the research results, translating them into a long-term impact.

MEASURING SOCIETAL IMPACT IN EUROPEAN UNION PROJECTS

In the EU assessment and evaluation, what we understand as “impact” has often been referred to as “relevance”. According to the European Commission's reports “Better Regulation “Toolbox” and “Applying relevance-assessing methodologies to Horizon 2020”, “relevance looks at the relationship between the needs and problems in society and the objectives of the intervention.” Indeed, it is indispensable to continuously screen and benchmark objectives and activities of the EU projects against major strategic goals and priorities of the European Commission. Thus, one of the major challenges is to assess the “relevance” of the framework programs, in order to verify to which extent the original objectives of the particular framework program still coincide with the current priorities and needs.

The general methodology for evaluation of relevance of the framework programs includes three major steps, which aim to determine the degree of compatibility of the framework program with the institutional perspective (Is the program in line with the EU and international priorities?), citizens' perspective (Is the program in line with the needs of the EU citizens?) and science and technological perspective (How well adapted is the program to the subsequent technological or scientific advances?). In order to respond to each of the questions, two sub-questions have been formulated, as the assessment of relevance requires to: (1) identify policy priorities, citizens' needs and scientific and technological advances in the first place, so that (2) the framework program could be put into perspective and benchmarked against the identified priorities, needs and advances.

Different methods have been employed for answering each of these questions. First, in order to identify EU and international priorities and assess the compatibility of the framework program with it, experts' exploratory approach and computer content analysis (text mining) are employed. Additionally, societal needs within the EU are also identified using on-line content analysis (Eurobarometer surveys and EC consultation reports, social media analysis). Besides the experts' exploratory approach; several other methods are used to assess the relevance of the framework program to the technological and scientific advances, such as the bibliometric analysis; social media content analysis; and patent analysis.

What the document specifically emphasizes is that the goals set at the beginning of the framework program do not necessarily correspond to the contemporary challenges, as the political priorities, societal needs and technological advances change over time. This is also true for most of the research projects in social sciences and humanities, designed to create a certain impact. But, by the time the project is finalized and the “impact” achieved, the problem might be “outdated” and no longer relevant for the society. Therefore, the “relevance” or impact analysis is an ongoing process, aiming to continuously question and adapt projects to better reflect current challenges and needs. Moreover, when designing a project, one has to take into consideration not only the current, but also the future relevance of it, and try to foresee future priorities, challenges and developments.

The *Better Regulation “Toolbox”* highlights the importance of identification and assessment of the most significant impact in the process of project/policy evaluation. The process consists of first mapping out all potentially relevant impacts and then selecting for the in-depth analysis of those which are likely to be significant. The key impacts for screening,

according to the document, maybe split into 3 major groups – economic, social and environmental. The selection of significant impacts is based on the relevance of the impact, absolute scope, relative size of expected impact for specific stakeholders and the importance of impacts for Commission horizontal objectives and policies. The key economic impact categories to be closely monitored include, amongst others, the impact on operating costs and conduct of business, the impact on administrative burdens, trade and investment flows, competitiveness, the position of SMEs, innovation and research, public authorities, consumers or macroeconomic environment. For the social impact, the Toolbox suggests monitoring the impact on employment, working conditions, effects on income, distribution, social protection and inclusion, governance, public health systems, security, education and training, culture and the social impact in third countries. The major environmental impacts include the impact on climate, air quality, water quality, biodiversity, soil quality, waste production and recycling, efficient use of resources, sustainable consumption, international environmental impacts, transport and energy use, animal welfare, prevention of environmental risks and the land use. Finally, it is possible to reflect on the impact in the field of fundamental rights, such as dignity, liberty of individuals, private and family life, freedom of expression and information, personal data protection, asylum, property rights, gender equality, children’s rights, administration and justice.

CONCLUSION

The aim of this article was to provide an initial overview of the main debates in the field of research evaluation and impact creation in social sciences and humanities. The existing evaluation tools and methods do not necessarily reflect the quality of transdisciplinary research nor encourage advances across the fields and innovative projects. This is why the number of scholars started advocating for the introduction of new evaluative criteria and methods. We aimed to identify these innovative strategies for evaluating research in social sciences and humanities, as well as the main challenges and dilemmas researchers face when it comes to assessing transdisciplinary research. It was concluded that while most of the new evaluation strategies still need to be re-shaped and put into practice, the societal impact has been a widely accepted tool for enhancing research quality. It has been increasingly used to assess research potential, outreach and practical implication and as such represents an important evaluation mechanism, out of which most of the funding became dependent. In conclusion, we analyzed some of the major mechanisms for assessing societal impact in EU projects, highlighting major impact categories and tools for their evaluation. Some of these strategies might be in future translated into the sphere of evaluation of research articles and smaller-scale projects, using the same categorization and assessment process.

ACKNOWLEDGMENT

This article has been written within the national project “Quality of Research in Social Science and Humanities”, funded by the Ministry of Science in Montenegro (No.01 – 2589/2 from 11 December 2017).

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UTILISING DIGITAL MEDIA AS A SECOND LANGUAGE (L2) SUPPORT: A CASE STUDY ON NETFLIX WITH TRANSLATION APPLICATIONS

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DOI: 10.7906/indecs.18.4.6
Regular article

Received: 22 April 2020.
Accepted: 5 August 2020.

ABSTRACT

Netflix, which has been increasing in popularity during recent years and has millions of viewers, is an international platform since it has multicultural films and their translations. Due to the content of TV series, films, documentaries, and various programs on Netflix, it appeals to the young and adult audiences and besides, offers unique options for children. This study aims to argue that the programs on Netflix are supportive, especially in learning and supporting a second foreign language. Second foreign language learning methods and language competence topics constitute the theoretical background. As a general theme, using videos, and movies in learning and developing foreign language is taken as a basis. Within the scope of this research, a questionnaire consisting of 8 questions to analyse the Netflix programs was used and given to a sample of 150 students studying translation in the English-Turkish language pair. These students are Netflix programs' audiences. The data obtained from the questionnaire has been analysed with the descriptive analysis method and a general situation assessment has been received concerning whether Netflix could help improve foreign language competence. As a result of this research, it has been determined that Netflix programs as a video-film category may contribute to the development of the second language. Thus, by using it in a controlled manner, Netflix may contribute to foreign language competence.

KEYWORDS

Netflix, digital media, language competence, foreign language education, second language (L2)

CLASSIFICATION

JEL: I29, Z13

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INTRODUCTION

The digital media industry continues to improve itself day by day, offering quite different options for people with special interests such as watching TV series and/or movies in their spare time. Once established, especially abroad, then maintaining the necessary localization processes, the serial-movie platforms have gained a great number of audiences and the users in Turkey. The reason why the audiences prefer such platforms can be predicted as the submission of the content in many languages with subtitles. Within the scope, using such videos and movies has been focused on teaching foreign languages, and supporting foreign language learning. In this study, Netflix programs, one of the leading names of digital platforms, and language teaching and translation applications working on these programs have been examined. However, a short survey has been carried out with 150 students, studying English-Turkish language pairs and using Netflix.

Netflix has grown tremendously during recent years. Especially the serials in different languages in different countries provide an excellent advantage for culture and language learning for people of all nationalities. A fan of this size allows the users not only to use their spare time but perhaps to improve foreign language knowledge. Since 1997, Netflix has been watched for low monthly price choices until today with the purpose of sales of movie DVD rental and sales services over the internet. It gives the users the chance to watch the broadcasts such as TV shows, programs, documentaries, TV serials and internet serials, animations, cartoons. It is accessible on Android Playstore and Apple versions for desktops, laptops and mobile phones on the internet. Since 2016, Netflix is available in 130 countries for offering global entertainment [1].

In a research conducted by Türkmen and Can, it is analysed and stated that to learn and develop foreign language usages, the majority of the students of the research group watch and follow foreign TV and/or internet serials, programs on the channels such as Dizibox, Netflix, Dizimag. According to the results received from the mentioned research, the audiences are visually confronted with the words and structures they watch and hear. They state that watching the contents in a foreign language with the subtitles as in the same language may prevent misunderstandings and help to learn and develop the pronunciations of what they watch [2].

Youtube, Ted Talks and Netflix applications and programs, especially subtitles, speech transcripts, and dubbing, which are examined for the use of videos in translation education, may have a significant impact on the competences of the students who have language and translation education. In this scope, Türkmen and Köktürk state that video supported applications and programs provide benefits to students who receive translation education, such as listening and understanding required during their education, acquiring various knowledge such as vocabulary knowledge in a foreign language, cultural competence in line with the text, text-subject, and transponder. Videos should be used consciously as course material in translation education. The videos watched by the students in the researches, as mentioned above, are videos prepared in the English language. Besides, it is seen that they open the English subtitle and follow the video or use the written text of the speech to follow the speech and use it in a way that contributes to the pronunciation of students who are educated in a non-native English language. While the students follow the videos, they watch them with subtitles in the same language, and they follow the words by hearing and looking. The video applications mentioned in this context, but not limited to, show that students often feel insufficient in performing verbal communication practices during their education period. Thus, following the method, such as using videos, films may contribute to the pronunciation usages of the students [3].

Research Questions

Under this research, the primary purpose is to learn whether utilizing the Netflix as a digital media for supporting the second language (L2) is possible or not. For this purpose, the following questions are asked:

- Does Netflix have any contribution to the foreign (second) language competence?
- What are possible for L2 learning by watching Netflix contents with the translation applications?
- How can the language learning applications be supportive for L2 learning and developing language competence on Netflix?
- What are the thoughts of students about Netflix as a foreign language supporter?

METHODOLOGY

A literature review was conducted on language learning strategies and language competence. Information about Netflix, which is a new digital media channel, has been received by analysing the digital platforms about the technology and video-film sector. This research has been carried out to question whether watching videos-movies in foreign languages contribute to foreign language learning and improving the language competence specific to Netflix. It has been conducted with a questionnaire with 150 students to evaluate the use of Netflix and language learning applications. Students have been chosen from the ones who watch Netflix programs and getting the same level of translation education. The survey consists of 8 questions. 6 of them are Yes-No questions, and 2 are open-answer ones. While preparing these questions, 3 Assistant Prof. from Zonguldak Bulent Ecevit University Foreign Languages and Cultures Department supported with their evaluations into the research. Their evaluations have been taken into account after presented the questions to them. They revised the questions at a minimal level. The questionnaire includes 8 questions. First one is about the program type they follow, the questions between 2-6 are asked as in Yes-No style. 7 and 8 are open-ended questions. The evaluations of these two questions are given a general perspective. The results obtained from the questions have been analysed depending on the descriptive analysis method. Within the context of descriptive analysis, the data obtained in the research are interpreted under the predefined themes or research questions. The descriptions made by interpreting the mentioned data are explained within the frame of the cause-effect relationship and in the way to reach detailed results [4]. The purpose of descriptive research is to describe a phenomenon and its characteristics [5]. Descriptive research includes certain types of research methods such as survey, correlation study, qualitative study, and content analysis. All this kind of types are different from the view of their data collection/analysis procedures, but not in data availability [6]. In this concern, the results are described, and they indicate the general view on utilizing Netflix as a digital media program for supporting and developing the following language competences of the students. This questionnaire does not include more detailed statistical analysis. This study aims to see and analyse the general status and views about utilizing Netflix by the university students who need to develop their second languages (English) as a case. In further studies, it is aimed to study in a more detailed statistical perspective with different digital media programs comparatively as a follow-up of this research.

RESEARCH GROUP

The research group of this study includes 150 students from Zonguldak Bulent Ecevit University Çaycuma Vocational School Applied English and Translation Program. This program is equivalent to the college level under universities. The vocational schools in

Turkey have 2-year period education in universities. All the students participate in this research are chosen from the same department in the same university. The questionnaire used in this study was applied on them under the concept of Computer Aided Translation Course they had in university. The questionnaire was sent to the students via e-mail. Totally there are 200 students from 2nd class in Applied English and Translation Program. Each of the students received the link of the questionnaire. They are chosen for this research voluntarily. They are chosen for this research since they need to develop their foreign language knowledge consistently and contemporarily. In the e-mail, they are asked to answer the questionnaire if they use Netflix accounts. The aforementioned students in this research, have at least B2-C1 level English knowledge. They have 1 year prep. class education and 2 years translation education.

LITERATURE REVIEW

When it is about technology and education, mobile devices come to the scene. Today such devices and their impact on their users cannot be ignored. In this research, Netflix, as a channel and mobile application in smart portable devices for language learning, is analysed and studied. In this concern, the convenient and individual nature of mobile phones offers them massive potential in supporting casual and deep-rooted learning blended with regular daily existence. Likewise, the utilization of versatile innovation gives learning and instructing backing to arrange students and learn action assets and to help the board assignments more generally [7, 8]. Considering the constructivist learning, students effectively build new ideas or thoughts dependent on their past and current knowledge [9]. Mobile phones empower students to be associated with a sensible setting, and all the while, giving intense apparatuses [7]. The students at that point, effectively construct their insight and make intuitive models. The constructivist paradigm centres around setting subordinate portable learning. For instance, joint effort and association in versatile learning through correspondence among the students or utilizing keen mobile phones, just as inquiries posed to inspect dynamic applications and critical thinking [10].

Mobile applications and mobile learning have an incredible place in language learning during recent years. It is seen on the researches carried out related to the learning technologies and the technologies in language and translation learning. In this sense, as it is known that language competence is required in many disciplines today. Albrecht Neubert emphasizes that language competence in the form of dictionary and similar studies as the awareness of the continuous changes that can be partially reflected in the source and target language. In particular, it refers to the syntactic and morphological gathering of the content in the languages as part of the linguistics for specific purposes [11]. According to the PACTE research group, being bilingual is defined as mastering all linguistic rules and more in two different languages. At the same time, while the bilingualist is the socio-linguistic, pragmatic, textuality, grammar and lexical structures required to communicate in two different languages. It is defined as complete comprehensive information [12].

When it is about learning a new language, the learning strategies should be considered and analysed and applied during the education process based on the technological improvements of today. There are different groups of learning strategies and language learning strategies in the education discipline. They are required to be adapted to the new conditions of education systems. As Oxford stated that learning strategies are classified into six categories: 1) *cognitive* including reasoning, analysis, summarizing; 2) *metacognitive* including self-planning, arranging, evaluating; 3) *memory-related* including grouping, associating, and using imagery; 4) *compensatory* including guessing, switching to L1; 5) *affective* including using music, laughter, meditation; and 6) *social* including becoming aware of other points of view [13, 14]. In this category, watching videos and films can take place

under an effective strategy. Regarding that, each assignment in the language learning environment requires exceptional learning system, and when a suitable procedure can be sent, learning will happen adequately. For the individuals who know about what system to use to turn out to be wholly engaged with, learning can be enjoyable. Besides, these students are more propelled than the individuals who are oblivious to the procedure underlying the learning [15]. As it is known that the communicative approach in language learning is a learner-centred approach in which the students require to develop different competencies such as communicative, grammatical, sociolinguistic, discourse, and strategy [14]. In this sense, the teacher and the lecturers should make their classrooms attractive to the students. They need to focus students on individual and collaborative learning goals to influence them [16].

At the point when the students deliberately pick techniques that fit their learning style and the L2, these methodologies become a helpful toolbox for dynamic, conscious, and intentional self-regulation of learning. Learning procedures can be ordered into six groups, such as cognitive, metacognitive, memory-related, compensatory, affective, and social [17]. L2 learner students need to capitalize on their style inclinations. Therefore, they should likewise expand themselves beyond their style inclinations. Supporting a wide range of in-classroom exercises that take into account distinctive learning styles, instructors can help L2 students to create the beyond safe place directed by their natural style inclinations. The key is efficiently offering an incredible assortment of exercises inside a learner-centred, communicative methodology [17, 18].

Regarding the studies and researches as mentioned earlier, in another study of the author of current research with the title of “Digital Media Competence and Translation Technologies in Translation Education”, it is seen that watching videos such as movies, series, music clips may contribute to the foreign language of the students during their daily life and learning processes. Such as broadcasts are proved to be supportive of creating environment cultural consciousness, whether consciously or unconsciously. In this concern, the audiovisual programs are accepted to be supportive for learning and developing foreign language during the language teaching and practising in creating the entertaining and instructive environment and support listening, comprehension and speaking skills for students [15].

However, during the literature review process of this study, it is seen that there are not many studies about Netflix and second language learning since this is a new and developing structure. In Japan, Gilbert Dizon had research titled as *Netflix and L2 learning: A Case Study* with the university students. According to the results of this research, the ability to download titles may enable students to use Netflix because of its being advantageous for time and places. This study indicates that the learners prefer watching L2 video through their portable technological devices such as smartphones and tablets, stating that mobile technology is one move ahead than desktop PCs [19].

Indeed, one of the most significant purposes of language education today is to create a productive, activated and a motivating learning environment to the students. Thus, they would do something on their own and the things that they enjoy while they are learning languages. In this regard, the educators, lecturers, teachers have a role which cannot be ignored to create such environments. It is required to make students discover how they would both enjoy and learn. This research aims to state and indicate that Netflix and the equivalent broadcasts can be used as a language learning material considering L2. It is known that, at certain times, the psychological and the external factors have adverse effects on the students during their learning processes in schools and courses, it is thought that such programs and applications may positively direct their interests on language learning.

TRANSLATIONS FOR NETFLIX

Netflix, whose audience and followers are increasing recently, is a service that enables them to watch numerous award-winning TV shows, movies, series, documentaries from internet-connected smartphones, tablets or computers. It does not compel Netflix viewers to watch advertisements. This program, which requires a paid membership, is free to use for the first month. It has an enormous monitoring capacity, accessible in more than 190 countries. It offers the possibility to pause and repeat broadcasts (series, movies, documentaries, shows, cartoons). Besides, there is the possibility of monitoring by installing on portable devices with iOS, Android or Windows 10 operating system. TV shows, movies, documentaries, series etc. broadcast on Netflix. It is possible to watch many publications with different language options in an optional way with subtitles and dubbing. While Netflix provides subtitles in many languages, it offers the possibility of dubbed viewing in 5-7 languages. Thanks to these features, it allows audiences to edit the subtitle and audio settings in the desired language, or watch the programs published in the original language or with the translation versions [1]. During the literature research of this study, any theoretical information about Netflix cannot be found since it has been studied recently. However, general knowledge about Netflix is received from its help pages on the official website. Besides, the knowledge about the translations for the Netflix programs are received from the interview evaluations on the current journal web pages related to the technology.

In this study, the focus is primarily on the English-Turkish language pair for the subtitle, and the dubbing of the original programs since the participants of the survey under this study are chosen from English-Turkish translation students. In this concern, primarily the interviews and the information on the translations of Netflix are evaluated from the general perspective. During the process of this research, many different kinds of Netflix programs such as serials, movies and the animations have been watched to see whether there are any differences between the subtitles and dubbings of them into Turkish. The differences derive from particularly about word choosing during the translation processes. The meanings are similar, but the words that are heard and seen are different sometimes.

As it is stated, Netflix has no office in Turkey. The Turkish procedural needs of Netflix are carried out by the local teams in the European countries. Netflix is working to provide the highest quality subtitle and dubbing service in more than 190 countries. Until six years ago it only supported English, Spanish and Portuguese. Today, services in more than 20 languages, including Turkish, Korean, Chinese, Arabic, Greek and Polish are provided. As for the source of translations, Netflix talks about two different options: The subtitles and dubbing of their original productions are carried out by the local partners it works with.

On the other hand, a significant part of its content consists of productions licensed from different content providers. Netflix states that they consider they receive all comments, criticisms or complaints, and they share them with their relevant units. Their members may convey their feedbacks about subtitle and dubbing directly to their relevant units by going to the monitoring activity from the account settings [20].

LANGUAGE AND TRANSLATION APPLICATIONS WORK ON NETFLIX

While Netflix is progressing in parallel with the development of the digital media throughout the world and gaining a large number of followers and the audiences, it is seen that specific supporter applications and the programs which would be used synchronized on Netflix have been gradually developed. Such applications and the programs can be found on Android and IOS

Playstore for free of charge. These applications and programs have begun to constitute developing supportive structures. The applications and the programs mentioned above are mainly focused on language learning. They are used for learning vocabulary while watching movies and series on Netflix. The advantages of these are seen as the subtitles are presented simultaneously with a translation, and by comparing the translation with the original voice and text, too many words can be assimilated in a short time. Another option is choosing who will translate; texts provided by automatic translators or translators who contribute to the program over the internet. By hovering over a word, the users can look in what language they want, and in this plugin, there is also the possibility of voice translation, that is by clicking on the word chosen, its pronunciation can be heard.

MATE is an application which translates the subtitles into the language chosen while watching on Netflix programs. It also provides learning the meanings of the words which are clicked on. The focus of *MATE* is learning the foreign languages via the movies, serials and similar programs for their users. First of all, using *MATE* is very easy to use. It is downloaded as a plug-in for Chrome, Firefox, Edge and Opera browsers. *Mate* is also available in application format for Mac and iOS devices. There is no need to do extra after downloading the plugin. Then open the content that is chosen from Netflix. At this point, the subtitles of the contents to be watched need to be preferred in the foreign language, not in (your) native language. After that, by clicking on the word selected, or on a sentence, the translation automatically appears on the screen without breaking the series or movie that continues behind. Moreover, it is possible to find almost all dictionary meanings of the word wondering via *Mate* [21].

On the other hand, the advantage mentioned is a Google Chrome plugin; *LLN*: Language Learning with Netflix. *LLN* allows the users to add subtitles both in the original language of the series watched on Netflix and in the native (your own) language. *LLN* aims to improve foreign language skills effectively and enjoyably by watching movies and series. By using *LLN*, it is possible to build the users' listening comprehension with thousands of hours of unique language context. After installation, while watching videos on the Netflix website, additional features for language learning are provided by *LLN*. Subtitles are displayed in two languages to allow the users to compare the original audio and text with their language translation. The extension allows users to listen to subtitles one by one and change the playback speed. There is a pop-up dictionary, and the extension suggests the most important words for learning. The 'Pro' mode allows additional options for subtitle translation, allowing to save words and expressions which will be featured whenever subtitles appear. Only Netflix membership and Google Chrome extension are necessary to use *LLN* [22]. However, in the Google Chrome Webstore, there are similar applications and programs can be used for language learning purposes via subtitle translations and vocabulary supports such as *Netflix Extension*, *Subtitles for Netflix*, *FINDFLIX-Netflix recommendations*, *Netflix Multi-Subtitles*, *Traktflix*, *Super Netflix*, *Random Netflix*, *Unsubtitle for Netflix*, *Netflix Subtitles Translator*, *Netflix Dual Subtitle for Learning Languages*, *Netflix Hidden Category Search*. The applications mentioned above can be analysed from the Google Webstore and can be used focusing on the purposes and the features of them.

EVALUATIONS OF THE QUESTIONNAIRE

The evaluations of the answers received from the students are given in tables and graphics. Under this concern, the first questions answers are given in Table 1, the YES-NO questions are given in with their frequencies and the percentages, and the last two open-ended questions are

analysed from a general perspective. By asking these questions, situation analysis on the users' using Netflix and the possible contributions to the foreign language is indicated as a case study.

Question 1. What Kinds of Programs Do You Follow on Netflix?

Table 1: The Programs Followed on Netflix.

Program	Frequency	Percentage, %
Documentaries (Foreign Language)	58	38,7
Documentaries (Turkish)	26	17,3
Serials (Foreign Language)	138	92,0
Serials (Turkish)	33	22,0
Movies (Foreign Languages)	113	75,3
Movies (Turkish)	43	28,7
Cartoons-Animations (Foreign Language)	54	36,0
Cartoons-Animations (Turkish)	17	11,3

As it is known that Netflix has different and current broadcasts such as documentaries, serials, movies, cartoons and the animations both in Turkish and in many different foreign languages. From the results received from the students, it is seen in Table 1 that the students mostly watch serials in a foreign language 92 %, then the movies in the foreign languages 75,3 % follows these percentages. In a further study about Netflix and audio-visual translation, the reason why mostly the movies and the serials are preferred can be analysed.

Question 2. Do You Open Subtitle Feature While Watching Movies, Serials or Documentaries in Foreign Language on Netflix?

The students are asked whether they use subtitles or not while watching the broadcasts that they prefer. For Question 2, 92 % of the students (138 people) answered Yes, and 8 % of them (12 people) answered No. This result indicates that the students mostly watch the broadcasts on Netflix with subtitles.

Question 3. In Which Language, Do You Often Use Subtitles on Netflix?

The students are asked in which language they use the subtitles while watching the broadcasts they prefer. For Question 3, 64 % of the students (96 people) answered their native language Turkish, and 36 % of them (54 people) answered in a foreign language. In these answers, especially the foreign language means English since these students have education in Turkish-English language pairs.

Question 4. Do You Use the “Language Learning With Netflix” Application or any Equivalent Version of Its Which Can Be Used on Netflix?

The students are asked whether they use Language Learning with Netflix application or any similar ones while they are watching the broadcasts they prefer. For Question 4, 19,3 of the students (29 people) answered Yes, 80,7 % of them (121 people) answered No. This result indicates that they generally do not know the language learning programs such as LLN, which may be beneficial for them while watching the broadcasts.

Question 5. Do You Think Watching Movies, Videos, Serials, etc. on Netflix in Foreign Language May Contribute to Learning and Improving Foreign Language?

In this question, it is asked that whether they think to watch the broadcasts in foreign languages may contribute to the foreign language learning competences of them. Since this is a leisure time activity, they may have advantages from watching broadcasts. 96 % of the students (144

people) answered Yes, while 4 % of them (6 people) answered No. This result may indicate that the students take advantage of watching their broadcasts on learning a foreign language.

Question 6. Do You Think Watching Movies, Videos, Serials, etc. on Netflix in Foreign Language May Contribute to Learning About Foreign Cultures?

In this question, it is asked that whether they think to watch the broadcasts in foreign languages may contribute to the foreign culture knowledge of them. Since this is a leisure time activity, they may have advantages from watching broadcasts. 99,3 % of the students (149 people) answered Yes while 0,7 % of them (1 person) answered No. This result may indicate that the students take advantage of watching their broadcasts on learning foreign cultures. Since the movies and serials in foreign languages are taken in different countries, such broadcasts may be informative on the lifestyles, the clothes, business lifestyles, meals, environmental differences, etc. about the cultures for the audiences.

Question 7. Could You Briefly Explain How You Use Netflix in Learning Foreign Languages and Culture?

As it is known the published books as hardcopies gradually give their places to the online ones. In this era, books are secondarily preferred for learning foreign languages. Especially the e-books, mobile applications, computer games, etc. are preferred. Recently, the audiences of the different broadcasts state that they watch these programs for learning and repeating foreign language knowledge. They state that by watching such programs, they gain both language competence and cultural knowledge since these programs are taken in different languages in different countries. The answers of the students for this question are evaluated from a general perspective. As the audiences of Netflix determine it, the broadcasts on Netflix can be used by language learners since they have the transcripts both in their native languages and in foreign languages. They state that they learn grammar and vocabulary and listening competence while watching the programs. A group of the ones who answer this question also states that they learn different accents of foreign languages such as American and British English by listening and watching these programs with their original subtitles.

On the other hand, besides learning language and listening skills, they state that they learn something about the cultures from the broadcasts. They learn about different cultures, especially following the traditional and periodical broadcasts. Since these programs are taken in foreign countries, they learn the lifestyles, religions, beliefs, sentimental values, food cultures, clothing styles, climates, social lifestyles from these broadcasts. They also indicate that they compare the social hierarchy and social order between the foreign cultures and their own cultures.

Question 8. What Do You Think About Turkish Translations (Dubbing and Subtitles) on Netflix Contents? Do You Think the Translations Are Sufficient? What Kind of Losses Are Experienced in The Translations From English to Turkish?

The answers of the students for this question are evaluated from a general perspective. In the case of a foreign language is known well by the audiences, the subtitles and the dubbings of the broadcasts in any other language may be seen as disagreeable. However, if the foreign language of the broadcasts is not well known by the audiences, it may not be problematic. In this concern, the ones, who have advanced level foreign language (English for this research), state that they lose confidence in the translations of the broadcasts. In general, it is seen that the translations may not reflect the same feelings with the original language. Here the point is the dubbing and subtitle translations. If the translators choose the word-for-word translation the audiences state that they feel bored. Thus, mainly the cultural differences and their effects

on the audiences are seen. Notably, it is stated that there are differences between the subtitles and the dubbings in the same language in a film. This is accepted as complicated and confusing for the audiences. This mentioned case gives rise to the thought that the translations in the language of the broadcast are carried out at different times and by different translators. It is mentioned that the audiences found the translations censored, and the meanings or the interpretations are not found clear in certain scenes.

CONCLUSIONS

Regarding the answers of the students using Netflix, it is seen that they try to get advantage from Netflix for language learning, although it is not their primary purpose while watching the programs on Netflix. As seen from the answers received for question 5 and 6 are interpreted in a general view. These questions are about contributing to watching movies, videos, serials, etc. on Netflix in a foreign language to learning about foreign languages and cultures. These questions have been answered in Yes-No form. In Question 7, the students were asked to explain briefly how they use Netflix in learning foreign languages and culture. This question aims to prove that the students use these broadcasts for developing their second language (English) besides entertainment purpose. Via watching TV programs, movies, serial or different kind of broadcasts, people may learn the second language, or they may develop their language knowledge. Watching broadcasts on Netflix is seen as advantageous for learning new terms, vocabulary and language usages. It may be beneficial for listening, grammar, vocabulary and also writing competencies while watching the spare time activities. As the students' state, via watching these broadcasts, they learn the casual language usages such as slangs, cultural differences, vocabulary and grammar.

These materials on Netflix can be used as educational materials if the lecturers control them. Specific programs can be chosen considering their course contents. These programs are thought to be beneficial and supportive for second language (L2) and also cultural competence for the audiences in this research. Specific applications and programs such as MATE and LLN can be used for vocabulary and grammar support of Netflix. During this process, watching such broadcasts may provide language and cultural themes learning in more relax and comfortable environments for the students since this is an entertainment and leisure activity. Since Netflix has advantages to use on any device connected to the internet such as desktops, TV, laptops and mobile phones, having the learning environment of the users' is up to themselves. Without having the stress of exams, questions and answers in the school and classroom environments classroom among their friends and in front of their lecturers, the students experience learning foreign languages where they feel comfortable. Young and adult university students can be assigned to do homework and work practice on Netflix. Indeed, it is foreseen that doing homework is often seen as a burden for students, and it can be possible with using a broadcasting source such as Netflix to inform them and support their language skills while doing a leisure time activity they like.

This research aims to analyse the general status and views about using Netflix broadcasts by the university students who need to develop their second languages (English) as a case. This research can be accepted as an introduction study for research chain on digital media broadcasts such as Netflix, Youtube, etc. When considered from this point of view, this research does not include different and detailed statistical analysis. The research content with especially determining the using state of Netflix broadcasts by university students from the view of second language developing. The evaluations and the results of the questions asked to the students aim to prove that such like broadcasts and channels can be supportive for second language learners if they are used with the purpose of education in a controlled manner.

For further researches, it is aimed to study from more detailed statistical perspectives with different digital media programs comparatively as a follow-up of this research. For further studies about Netflix and language and/or translation, it is suggested to study the translation differences between the dubbings and the subtitles of specific programs. This research necessitates that the translation differences can be analysed based on gender and language theme. Is there any censor on the translations of the programs on Netflix or not? It can also be studied how the translations of Netflix can be developed and used for language and translation education.

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FORECASTING STOCK MARKET INDICES USING MACHINE LEARNING ALGORITHMS

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DOI: 10.7906/indecs.18.4.7
Regular article

Received: 15 June 2020.
Accepted: 14 July 2020.

ABSTRACT

In recent years machine learning algorithms have become a very popular tool for analysing financial data and forecasting stock prices. The goal of this article is to forecast five major stock market indexes (DAX, Dow Jones, NASDAQ, Nikkei 225 and S&P 500) using machine learning algorithms (Linear regression, Gaussian Processes, SMOreg and neural network Multilayer Perceptron) on historical data covering the period February 1, 2010, to January 31, 2020. The forecasts were made by using historical data in different base period lengths and forecasting horizons. The precision of machine learning algorithms was evaluated with the help of error metrics. The results of the analysis have shown that machine learning algorithms achieved highly accurate forecasting performance. The overall precision of all algorithms was better for shorter base period lengths and forecast horizons. The results obtained from this analysis could help investors in determining their optimal investment strategy. Stock price prediction remains, however, one of the most complex issues in the field of finance.

KEY WORDS

machine learning, neural networks, stock market indices prediction

CLASSIFICATION

JEL: C53, G17

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INTRODUCTION

In recent years incredible progress in the field of artificial intelligence, machine learning and neural networks has been seen. Machine learning, as a subset of artificial intelligence, is closely related to computational statistics related to the building of algorithms which learn on training data to make predictions. It is a current application of artificial intelligence concerned with the discovery of models, patterns and other regularities in data [1]. Machine learning is one of the most exciting recent technologies in artificial intelligence and has many applications that we make use of daily such as virtual personal assistants, video surveillance, social media services, online customer support, etc. [2]. Machine learning algorithms have become a very popular tool for analysing financial data and forecasting stock prices in the last few years [3]. The rapid growth of information technology and the Internet lead to the fast development of computer science methods. Neural networks are efficient methods for stock market prediction mostly implemented in forecasting stock prices and returns. The backpropagation algorithm is most frequently methodology used. The benefits of the artificial neural network are their ability to predict stock price movements even in situations with uncertain data [4]. The prediction of stock market prices and indexes is, however, a difficult task because various factors affect the stock price formation.

The goal of this article is to forecast stock market indexes using machine learning algorithms. Weka is a collection of machine learning algorithms for various data mining tasks such as data pre-processing, classification, regression, clustering, associate rules, visualization and forecasting. The algorithms are Linear regression, Gaussian Processes, SMOreg and neural network Multilayer Perceptron. In the article, the prediction of five major stock market indexes (DAX performance-index (DAX), Dow Jones Industrial Average (Dow Jones), NASDAQ Composite (NASDAQ), Nikkei 225 and S&P 500) will be made using historical data from February 1, 2010, to January 31, 2020. The prediction will be made separately for each of observed major stock market indexes using historical (training) data for three different periods (ten, five and one years) using machine learning algorithms. The forecast will be made for 5, 10, 15 and 20-time units (days) in the future. In that way, it will be inspected how well selected forecasting approaches are performing for different forecasting horizons. The forecasting precision of machine learning tools will be evaluated using MAE, MSE and MAPE error metrics. It is expected that machine learning algorithms will have a high level of precision in predicting the future values of major stock market indexes. The novel in this article in regards to the previous research is more rigorous analysis of stock market indices forecasting using machine learning algorithms. In the article the comparison of machine learning algorithms' efficiency was made using historical training data on a longer and medium time period (10, 5 and 1 year) and by dividing the evaluations on training and held-out training 0,3 data for five stock market indices (DAX, Dow Jones, NASDAQ, Nikkei 225 and S&P 500). The robustness of the analysis is evident in using various error metrics (MAE, MSE and MAPE) for evaluation of forecasting precision of machine learning algorithms in five, ten, fifteen and twenty day horizon forecasts in the future. In this way the efficiency of machine learning algorithms was examined in a more comprehensive way in regards to the previous research. Article is structured in five chapters. After the introduction, literature review elaborates on the application of machine learning techniques in stock market prediction. In the methodology and data section, the main characteristics of data and data sources are explained. Besides, the preparation of data for the analysis in a detail are explained the main features of machine learning algorithms. In the results and discussion section, descriptive statistics of data is displayed first after which the individual forecasting performance for the market indices and

comparison of forecasting results between the market indices is presented. The final chapter presents concluding remarks, gives limitations of article and guidelines for future research.

LITERATURE REVIEW

In [5] built a model using a decision tree classifier and historical data of three major companies listed in the Amman Stock Exchange (ASE). The proposed model could be a helpful tool for investors in the stock market to decide when to buy or sell stocks. The stock market price prediction ability of artificial neural networks before and after demonetization in India [6] by observing nine stocks and CNX NIFTY50 index was investigated. Multilayered neural networks were trained by the Levenberg-Marquardt algorithm. The networks proposed efficiently predicted the close price and worked best for high volatile market conditions. A predictive study of the principal index of the Brazilian stock market [7] with the help of artificial neural networks and adaptive exponential smoothing method was performed. The objective was to compare the forecasting performance of both methods by evaluating the accuracy of both methods to predict stock market returns. The results showed that both methods produced similar results in predicting the index returns. In [8] the ensemble learning algorithm to increase predictive efficiency developed. Twelve indicators are ranked by market participants using the VIKOR method. The importance of each indicator was based on specified nose and output values. The results have shown that OBV, CCI and EMA indicators are very important. Furthermore, the SVM method of machine learning showed the superiority of the results in prediction accuracy.

Using Rapidminer tool [9] examined and applied different prediction models techniques using stock market historical prices giving recommendations for buying or selling in the stock market. Comparing different predictive functions they found that deep learning function predicted stock price more accurately than other functions. According to [10] different techniques for stock prediction were classified categorically in time series, neural network and its variations and hybrid techniques (the combination of neural network with different machine learning techniques). It was shown that the neural network was the best technique to predict stock prices, especially in the case when de-noising schemes are applied with the neural network. Five methods of analyzing stocks to predict day's closing price [11] were combined. Those are Typical Price (TP), Bollinger Bands, Relative Strength Index (RSI), CMI and Moving Average (MA). The results showed that algorithms predicted closing price in more than 50 % of cases with a high level of significance. Recurrent neural networks with character-level language model pre-training for both intraday and interday stock market forecasting were explored [3]. It was shown that the use of character-level embeddings was promising and competitive with other complex models which use technical indicators and event extraction methods.

The authors [12] predicted the Turkish stock market BIST 30 Index using deep learning where features are selected from common important technical indicators. They trained and tested their model to outperform other techniques such as an artificial neural network (ANN) concluding that deep learning has proved itself as a promising solution for complex problem-solving. A comprehensive survey of more than 150 articles on machine learning application to financial markets forecasting was made [13]. Machine learning algorithms tend to outperform traditional stochastic methods in financial market forecasting. Moreover, on average recurrent neural networks outperformed feed-forward neural networks as well as support vector machines. The profitability of artificial neural networks on the Taiwan Weighted Index and in the S&P 500 was investigated [14]. The authors created an efficient and inexpensive method for investors to ensure a good investment return and found that the trading rule based on artificial neural networks generates higher returns than the buy-hold strategy. Neural networks to forecast S&P

and Gold futures in the period of 90 months were employed [15]. The forecasted parameters for the networks relied on 15 months of patterns while network forecast performance was tested and evaluated over a period of 75 months. The networks were able to correctly predict the sign of the price change in 61 % and 75 % of the times for gold trade and the S&P index. A method of feature selection for stock indexes and deep learning model to do sentiment analysis was proposed [16]. An accurate stock trend prediction method chosen was LSTM (Long Short-term Memory). Two approaches for measurement and forecasting of realized variance are Heterogeneous AutoRegressive model (HAR-RV) and Feedforward Neural Networks (FNNs), [17]. The application was made for the DAX index. Compared to traditional models FNN-HAR-type models had better accuracy but only on the sample data. Conditional Value-at-Risk (CVaR) method was applied for the Croatian stock market on the sample of 29 stocks grouped into 8 sectors in three different periods. The results have shown that sectors that are risky in the period of economic growth are not the same sectors that are risky during the period of economic crisis or stagnation, [18]. In this article a comprehensive approach for forecasting of stock market indices will be made by applying machine learning algorithms.

The methodology applied in the article builds on previous attempts in the empirical literature by employing a comprehensive and extensive approach to analysis of major stock market indices. The comparison of machine learning algorithms' efficiency was made by using longer historical time-data series for five stock market indices, dividing the data on training and held-out training dataset, expanding the forecast horizon from five to twenty days and implementing different error metrics (MAE, MSE and MAPE).

DATA AND METHODOLOGY

Following the research aim of the article to forecast major stock market indexes using machine learning techniques and in order to inspect the successfulness and usability of different forecasting approaches, two main requirements should be fulfilled. The first requirement is the availability of long enough time series. The second requirement is that there are no many time series breaks or periods with no data availability. In order to meet both criteria, it has been decided that in the article data related to five major world market indices are going to be observed and analysed. Following five market indices are chosen: DAX performance-index (DAX), Dow Jones Industrial Average (Dow Jones), NASDAQ Composite (NASDAQ), Nikkei 225 and S&P 500. The data for the selected market indices are taken from the Yahoo! Finance web page [19-23]. Despite the fact that all data are taken from the same source, the observed market indices values are given in the national currencies. So, DAX is given in euros, Dow Jones, NASDAQ and S&P 500 are in US dollars, whereas Nikkei 225 is given in yens. The analysis in the article is based on historic data of various lengths. The reason for using historic time series data of different lengths is to inspect the accuracy of used forecasting approaches when a different number of training data is used as a base for calculating forecasts. Overall, three database periods are observed in the article: long, medium and short. The long base period includes historical data for the period of 10 years, the medium base period includes data for five years, whereas the short base period includes historical data from just one year. Here the 10 years base period covers historical data from February 1, 2010, to January 31, 2020, the five years base period includes data from February 1, 2015, to January 31, 2020, and the one-year base period includes historical data from February 1, 2019, to January 31, 2020. It has to be emphasized that in the article daily close prices adjusted for splits are observed only. For the analysis, the data are converted from .xls and .csv formats into .arff format. The process of preparation of DAX index data for .arff format is presented in a few rows of commands in Figure 1.

```

@relation DAX
@attribute date date "yyyy-MM-dd"
@attribute close numeric
@data
2010-02-01,5654.479980
2010-02-02,5709.660156
2010-02-03,5672.089844
2010-02-04,5533.240234
2010-02-05,5434.339844
...
2020-02-01,13204.76953
2020-01-28,13323.69043
2020-01-29,13345.00000
2020-01-30,13157.12011
2020-02-02,12981.96972
    
```

Figure 1. Preparation of DAX stock market index data.

In Figure 2 is illustrated system framework for major stock market indexes prediction containing input stock market data, timestamp, periodicity, lag and overlay which are inserted into the system to forecast data.

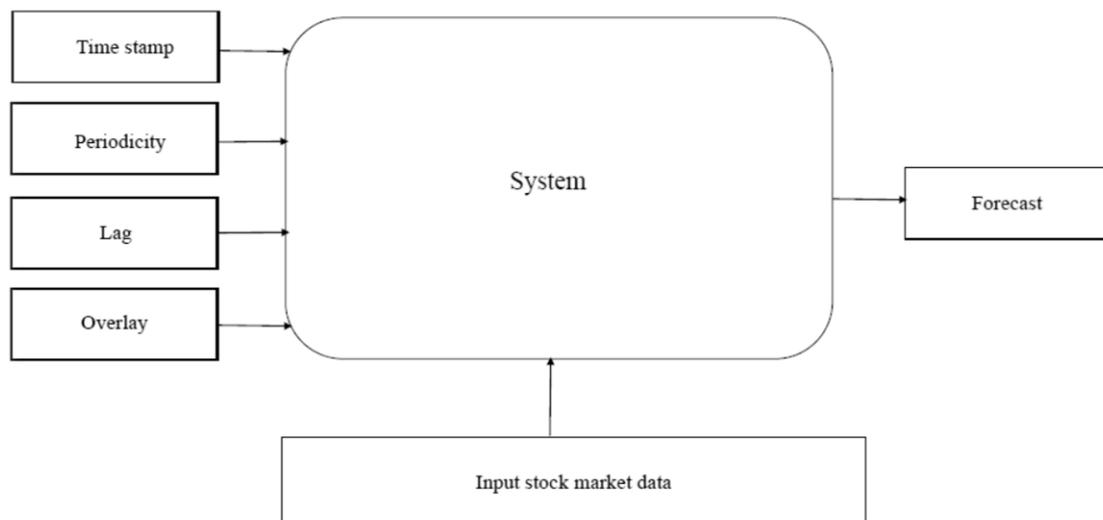


Figure 2. System framework.

The process of forecasting is conducted in Weka, version 3.8.4 software [24] with installed timeseriesForecasting package version 1.0.27 [25]. In the basic configuration window, it has been chosen that 5, 10, 15 and 20-time units (periods) should be forecasted in the future. In that way, it will be inspected how well selected forecasting approaches are performing for different forecasting horizons. As a timestamp the option „<Use an artificial time index>“ is used but under periodicity, the option „Daily“ is selected. Under the advanced configuration window, four base learner configurations or four different forecasting approaches are selected. To enable comparability and repeatability of the research default settings of the base learner configurations are used. Following four base learner configurations are used: Gaussian processes for regression (Gaussian processes), linear regression for prediction (Linear regression), the backpropagation to learn a multi-layer perceptron to classify instances (Multilayer perceptron) and support vector machine for regression (SMOreg).

Gaussian process for regression is a Bayesian or nonparametric approach to regression which becomes often used in the area of machine learning [26]. When the Gaussian process for regression is applied, the prior of the Gaussian process should be specified. Here the prior mean is assumed to be equal to the training data's mean. On the other hand, linear regression is one of the most commonly used traditional predictive models [27].

In the linear regression models, the association between the output variable and explanatory variables is assumed to be estimated with a linear line. It is assumed that the distances of actual data values and the regression line is minimized. Here the simple linear regression model is assumed in which output variable is the close price of an observed market index whereas the explanatory variable is time. The multilayer perceptron is a supervised learning algorithm that learns by training on a dataset. A multilayer perceptron has consisted of an input layer and an output layer. Between those two layers, it can be found one or more non-linear layers which are called hidden layers.

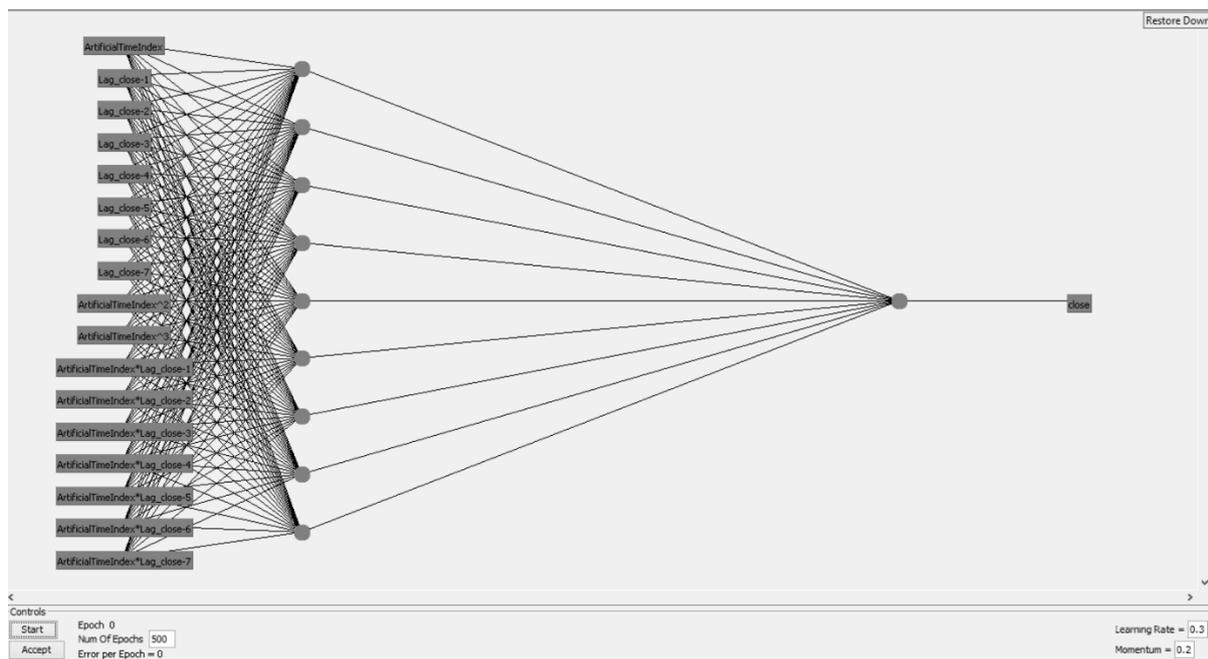


Figure 3. Prediction of DAX stock market index Multilayer perceptron (made by authors using WEKA interface).

The backpropagation is a learning algorithm which is often used at multilayer perceptron for finding the minimum error function. A detailed explanation of steps in multilayer perception with a hidden layer is shown in [28]. The sequential minimal optimization (SMO) is an iterative algorithm for solving regression problems by using support vector machine proposed by [29].

The analysis is conducted in two ways. The first way is to include all data as base or training data. In a second way, 30 % of the training data has been held out from the end of the series to form an independent test set. To evaluate used forecasting approaches following forecasting errors are used: mean absolute error (MAE), mean squared error (MSE) and mean absolute percentage error (MAPE). All forecasting errors are calculated by observing actual and forecasted values in the certain forecast horizon (5, 10, 15 or 20 days). By observing forecast errors in different forecast horizons, it will be inspected how the precision of a certain forecasting approach is changing with the change in the forecast horizon. In that way, it will be possible to conclude whether it is appropriate to use certain forecasting approach for forecasting more periods in the future or should it should be used only for short forecasting horizons.

Mean absolute error is calculated as an average of absolute differences between actual and forecasted values. Mean squared error takes into account an average of squared differences of actual and forecasted values. Mean absolute percentage error is calculated as an average of absolute differences between actual and forecasted values divided by actual values and multiplied by 100. Because the observed market indices are not all given in the same units, mean absolute error and mean squared error are going to be used to evaluate forecasting approaches for each market index separately. On the other hand, the mean absolute percentage error is going to be used to compare results between the market indices as well. In Equations 1-3 are presented formulas for calculation of MAE, MSE and MAPE values.

$$MAE_j = \frac{1}{N} \sum_{i=1}^N |\bar{Y}_i - Y_i|, \quad (1)$$

$$MSE = \frac{1}{N} \sum_{i=1}^N (\bar{Y}_i - Y_i)^2, \quad (2)$$

$$MAPE = \frac{1}{N} \sum_{i=1}^N \left| \frac{\bar{Y}_i - Y_i}{Y_i} \right| \cdot 100, \quad (3)$$

where \bar{y}_i is the predicted value and Y_i is the observed value for the number N of observations.

In Table 1 the interpretation of MAPE values according to the range of observed errors is explained.

Table 1. Interpretation of MAPE values.

MAPE value	Interpretation
< 10	Highly accurate forecasting
10-20	Good forecasting
20-50	Reasonable forecasting
> 50	Inaccurate forecasting

The value of MAPE lower than 10 can be interpreted as highly accurate forecasting, the value of MAPE in the range of 10-20 can be interpreted as good forecasting, the value in the range of 20-50 is reasonable forecasting while the value of MAPE higher than 50 can be interpreted as inaccurate forecasting.

RESULTS AND DISCUSSION

DESCRIPTIVE STATISTICS

The close values of the five market indices (DAX, Dow Jones, NASDAQ, Nikkei 225 and S&P 500) are observed in three different periods. Therefore, three descriptive statistics analyses have been conducted. The descriptive statistics results are shown in Tables 2, 3 and 4. In Table 2 descriptive statistics results by observing a period of 10 years is given whereas in Table 3 descriptive statistics results are given by taking into account period of 5 years. In Table 4 descriptive statistics results are presented for taking into account close daily values of the observed market indices in the period of one year.

The descriptive statistics analysis results, which are given in Table 2, include close daily values in the 10 years from 1.2.2010 to 31.1.2020. Therefore, those results are presenting the situation in the long term. Due to a different number of working days, the count of daily data is different among the observed market indices. However, there are no large differences in the data count between the given market indices. Still, the coefficients of variation values reveal that in the long term the close daily prices of market indices have high variability (or volatility) level. The highest variability level in the observed period had NASDAQ (41 %) whereas the lowest variability level had DAX (25 %). The distributions of close daily prices for stock market indices DAX, Nikkei 225 and S&P 500 seem to be approximately symmetric whereas data distributions of Dow Jones and NASDAQ seem to be weak and positively asymmetric. All five observed data distributions are flatter than the standardized normal distribution is.

Table 2. Descriptive statistics of the five observed stock market indices daily values, close price, data from 1.2.2010. to 31.1.2020.

Statistics	DAX	Dow Jones	NASDAQ	Nikkei 225	S&P 500
Count	2,533	2,518	2,518	2,449	2,518
Mean	9,593	17,755	4,800	15,887	1,980
Standard deviation	2,387	5,207	1,909	4,959	596
Coefficient of variation	25	29	40	31	30
Median	9,783	17,078	4,654	16,386	1,995
Minimum	5,072	9,686	2,092	8,160	1,023
Maximum	13,577	29,348	9,402	24,271	3,330
Skewness	-0,14	0,43	0,45	-0,12	0,22
Kurtosis	-1,32	-0,96	-0,96	-1,39	-1,06

Table 3. Descriptive statistics of the five observed stock market indices daily values, close price, data from 1.2.2015. to 31.1.2020.

Statistics	DAX	Dow Jones	NASDAQ	Nikkei 225	S&P 500
Count	1,263	1,259	1,259	1,224	1,259
Mean	11,644	21,923	6,381	20,167	2,473
Standard deviation	1,076	3,788	1,313	2,192	368
Coefficient of variation	9	17	21	11	15
Median	11,815	21,753	6,314	20,307	2,453
Minimum	8,753	15,660	4,267	14,952	1,829
Maximum	13,577	29,348	9,402	24,271	3,330
Skewness	-0,36	0,06	0,22	-0,30	0,21
Kurtosis	-0,81	-1,47	-1,28	-0,82	-1,16

The descriptive statistics analysis results, given in Table 3, are calculated based on close daily market indices values in the period from 1.2.2015 to 31.1.2020. The results are showing that the variability level of close daily prices is much lower in this 5-year period than in the 10-year period. The lowest variability level in this 5-year period had DAX (9 %) whereas the highest variability level had Nikkei 225 stock market index (25 %). All observed stock market indices had distributions of close daily prices almost symmetric expect DAX index for which data distribution is weak and negatively asymmetric. As in the 10-years period, all data distributions are flatter in comparison to the standardized normal distribution.

In Table 4 the results of the descriptive statistics are given for the period of just one year where the close daily prices are observed from 1.2.2019 to 31.1.2020. In this short term,

Table 4. Descriptive statistics of the five observed market indices daily values, close price, data from 1.2.2019. to 31.1.2020.

Statistics	DAX	Dow Jones	NASDAQ	Nikkei 225	S&P 500
Count	251	252	252	241	252
Mean	12,319	26,773	8,128	21,948	2,969
Standard deviation	658	1,046	496	1,048	150
Coefficient of variation	5	4	6	5	5
Median	12,264	26,573	8,034	21,617	2,941
Minimum	10,907	24,815	7,264	20,261	2,706
Maximum	13,577	29,348	9,402	24,084	3,330
Skewness	0,19	0,57	0,79	0,57	0,59
Kurtosis	-0,92	-0,44	0,16	-0,88	-0,32

coefficients of variation values are showing that close daily prices have low variability for all five observed market indices. However, all five data distributions of close daily prices are more skewed than they were in the medium (5 years) and long-run (10 years). Only the distribution of close daily prices for NASDAQ stock market index is less flat than the standardized normal distribution whereas the other four data distributions are flatter.

INDIVIDUAL FORECASTING PERFORMANCE FOR THE MARKET INDICES

In this chapter for each observed stock market index the most precise forecasting approach is emphasized. The best forecasting approaches are listed separately according to the mean absolute error and the mean squared error criteria. In other words, in Tables, A1-A5 in the Appendix are given forecasting approaches for which the lowest error values for different situations are achieved. The best forecasting approaches are listed by taking into account forecast horizons of 5, 10, 15 and 20 days. Furthermore, base period lengths of 1, 5 and 10 years have been taken into account as well. Finally, the fact of whether all historic data or just 70 % of them has been involved in the calculation of forecast values has been also observed. It has to be emphasized that the exact results of mean absolute errors and mean squared errors are not given here due to article length limitations but the data are available upon request.

In Table A1 in Appendix the best forecasting approaches for DAX are given. Both observed errors, mean absolute error and mean squared error, led to the choice of the same forecasting approach in all cases but the last one. If all data are used to calculate forecasts, SMOreg approach has shown to be the best solution if data from 10 years are observed. On the other hand, multilayer perceptron turned out to be the most precise forecasting approach when data only from one year are observed. If 30 % of the training data has been held out from the end of the series, it turned out that linear regression is the most precise when data from 10 years are used, multilayer perceptron is the best solution for time series of 5 years, whereas SMOreg is the most appropriate for short time series with a length of one year. In Table A2 in Appendix the best forecasting approaches for Dow Jones are listed. It has been shown that, when all data are observed, multilayer perceptron is the most precise forecasting approach when the base period length is 5 and 10 years. However, this is valid only if the forecast horizon is shorter than 20 days. On the other hand, when 30 % of the training data has been held out from the end of the series SMOreg turned out to be the most appropriate forecasting approach in most cases. According to the results from Table A3 in Appendix, where the best forecasting approaches for NASDAQ are shown when all data are observed, multilayer perceptron is the best solution when forecasts are based on a long period (10 years), SMOreg for the medium-long period (5 years) and Gaussian processes for short period (one year). When 30 % of the training data has been held out from the end of the series, Gaussian processes turned out to be the most precise forecasting approach for short period whereas in other situations SMOreg seems to be the best choice. Table A4 in Appendix contains a list of best forecasting approaches for Nikkei 225. When all data are used, it can be concluded that SMOreg is the best forecasting approach when forecasts are based on data from medium-long period. However, no other pattern can be recognized. On the other hand, when 30 % of the training data has been holding out from the end of the series, Gaussian processes turned out to be the most precise forecasting approach when forecasts are based on data from the short period (one year), SMOreg for forecasts based on data from the medium-long period (5 years) and linear regression is the best solution for forecasts based on data from the long period (10 years). In Table A5 in Appendix the best forecasting approaches for S&P 500 are listed. It turned out that, when all data as a base for forecasts are used, multilayer perceptron is the best solution when forecasts are based on data from the long period (10 years). In other cases, Gaussian processes approach

seems to be the most precise. On the other hand, when 30 % of the training data has been holding out from the end of the series, Gaussian processes turned out to be the most precise forecasting approach when forecasts are based on data from the short period (one year), linear regression is appropriate for forecasts based on data from the medium-long period (5 years) and linear regression is the best solution for forecasts based on data from the long period (10 years).

COMPARISON OF FORECASTING RESULTS BETWEEN THE MARKET INDICES

To compare the best forecasting approaches between the observed market indices, the mean absolute percentage error was used. The main reason for that can be found in the fact that not all observed market indices are given in the same units (US dollars, euros, yens). In this way, the direct comparison between the observed market indices can be made. In the following tables, Tables 5-10, mean absolute percentage error values for the observed market indices for different base period lengths (1, 5 and 10 years) are given. Besides, the demarcation between situations when all data as base or training data are used and when 30 % of the training data has been holding out from the end of the series is observed as well. In the aforementioned tables, the lowest values of mean absolute percentage errors for each observed market index and four forecast horizons are bolded.

Table 5. Mean absolute percentage errors for the five observed market indices, evaluation based on all data from 1.2.2010. to 31.1.2020. Base period length is 10 years, bolded values are the lowest values of market indices for certain forecast horizon.

Forecast horizon / Forecasting approach	Market index				
	DAX	Dow Jones	NASDAQ	Nikkei 225	S&P 500
5 days					
Gaussian processes	4,76	8,08	5,40	13,45	6,10
Linear regression	3,09	2,32	4,37	1,56	3,43
Multilayer perceptron	7,14	0,72	1,25	1,11	1,06
SMOreg	2,75	2,14	3,14	1,32	2,24
10 days					
Gaussian processes	39,77	17,68	11,42	74,79	16,36
Linear regression	4,20	2,84	5,97	1,98	4,61
Multilayer perceptron	11,21	0,57	1,40	0,84	1,08
SMOreg	3,68	2,53	4,10	1,37	2,87
15 days					
Gaussian processes	269,63	26,19	16,80	412,00	32,04
Linear regression	4,67	2,70	6,41	1,74	4,77
Multilayer perceptron	14,25	1,44	1,63	1,50	1,22
SMOreg	3,97	2,37	4,10	1,32	2,83
20 days					
Gaussian processes	2.043,17	31,63	21,92	2.504,69	55,50
Linear regression	4,32	4,06	5,31	3,11	4,54
Multilayer perceptron	14,77	4,60	4,11	3,86	3,87
SMOreg	4,06	4,10	4,35	3,33	3,97

According to the results from Table 5, it can be concluded that multilayer perceptron should be used as the most precise forecasting approach when long base periods are used. However, this choice is justified only for short forecast horizons. Furthermore, it should be mentioned that this conclusion is valid for four out of five observed market indices. Namely, in this case, SMOREG turned out to be the best choice for forecasting DAX.

Table 6. Mean absolute percentage errors for the five observed market indices, evaluation based on all data from 1.2.2015 to 31.1.2020. Base period length is 5 years, bolded values are the lowest values of market indices for certain forecast horizon.

Forecast horizon / Forecasting approach	Market index				
	DAX	Dow Jones	NASDAQ	Nikkei 225	S&P 500
5 days					
Gaussian processes	1,08	7,30	4,97	5,55	0,46
Linear regression	2,78	2,24	3,81	1,74	2,61
Multilayer perceptron	2,03	1,33	4,51	2,31	2,14
SMOREG	2,66	2,23	3,12	1,56	2,22
10 days					
Gaussian processes	1,26	13,82	10,23	11,65	0,61
Linear regression	3,74	2,71	5,10	2,44	3,45
Multilayer perceptron	2,37	1,26	6,25	3,88	2,80
SMOREG	3,60	2,72	4,18	1,98	2,97
15 days					
Gaussian processes	2,83	18,22	14,47	18,06	0,76
Linear regression	4,09	2,56	5,31	2,23	3,41
Multilayer perceptron	2,31	1,26	6,80	4,43	2,80
SMOREG	3,91	2,58	4,28	1,75	2,98
20 days					
Gaussian processes	6,77	21,47	18,51	24,27	3,00
Linear regression	4,06	4,05	4,77	3,15	4,07
Multilayer perceptron	3,40	3,64	5,63	3,74	3,85
SMOREG	4,02	4,03	4,31	3,05	3,87

In Table 6 base period length is reduced from 10 to 5 years and conclusions became not so straightforward. For NASDAQ and Nikkei 225 the most precise forecasting approach turned out to be SMOREG whereas for Dow Jones that is multilayer perceptron and for S&P 500 Gaussian processes. Those conclusions remained the same for all four observed forecast horizons.

By reducing the base period length to one year the general conclusion is even more difficult to bring. The results from Table 7 are not consistent across the observed market indices. In the short forecast horizons, Gaussian processes and SMOREG forecasted well. However, for longer forecast horizons multilayer perceptron turned out to be the most precise forecasting approach.

In Table 8 the values of mean absolute percentage errors are given when the base period length is 10 years but when 30 % of the training data has been holding out from the end of the series. The results are consistent through all forecast horizons. For Dow Jones, NASDAQ and S&P 500 the most precise forecasting approach is SMOREG whereas for DAX and Nikkei 225 the most precise forecasting approach is linear regression.

Table 7. Mean absolute percentage errors for the five observed market indices, evaluation based on all data from 1.2.2019. to 31.1.2020. Base period length is one year, bolded values are the lowest values of market indices for certain forecast horizon.

Forecast horizon / Forecasting approach	Market index				
	DAX	Dow Jones	NASDAQ	Nikkei 225	S&P 500
5 days					
Gaussian processes	3,44	1,22	1,26	5,29	0,81
Linear regression	1,82	1,27	1,56	1,17	1,00
Multilayer perceptron	0,92	2,96	2,40	1,27	2,11
SMOreg	1,53	1,00	1,72	1,00	1,04
10 days					
Gaussian processes	3,23	1,20	1,62	6,43	0,58
Linear regression	2,35	1,22	1,77	0,98	1,01
Multilayer perceptron	1,28	3,30	2,86	1,41	2,17
SMOreg	1,84	0,75	2,05	1,58	1,14
15 days					
Gaussian processes	2,69	1,67	1,80	6,98	0,93
Linear regression	2,43	1,29	1,90	1,34	1,15
Multilayer perceptron	1,49	2,88	2,85	1,29	1,95
SMOreg	1,66	1,26	2,11	3,20	1,25
20 days					
Gaussian processes	5,22	4,71	3,89	9,63	3,79
Linear regression	3,46	3,97	4,14	3,53	3,74
Multilayer perceptron	2,84	4,83	4,00	2,84	3,64
SMOreg	3,40	4,29	4,22	6,40	3,83

Table 8. Mean absolute percentage errors for the five observed market indices, evaluation based on 0,3 training data from 1.2.2010. to 31.1.2020. Base period length is 10 years, bolded values are the lowest values of market indices for certain forecast horizon.

Forecast horizon / Forecasting approach	Market index				
	DAX	Dow Jones	NASDAQ	Nikkei 225	S&P 500
5 days					
Gaussian processes	8,34	23,24	154,28	92,72	80,44
Linear regression	3,88	14,09	17,88	1,61	13,40
Multilayer perceptron	6,74	19,20	35,15	7,95	17,34
SMOreg	6,10	6,03	6,82	4,30	6,65
10 days					
Gaussian processes	88,06	123,35	1.156,68	666,65	607,60
Linear regression	5,36	18,10	22,91	2,11	16,93
Multilayer perceptron	7,68	24,10	40,82	9,21	22,02
SMOreg	9,53	9,42	10,64	7,51	10,49
15 days					
Gaussian processes	926,64	645,28	9.869,29	5.383,52	5.128,98
Linear regression	6,05	19,44	24,75	1,87	18,09
Multilayer perceptron	8,17	25,77	41,79	9,80	23,86
SMOreg	12,09	11,73	13,39	9,58	13,15
20 days					
Gaussian processes	11.624,54	3.757,37	97.448,91	50.289,99	50.370,14
Linear regression	5,21	18,25	24,02	3,14	16,80
Multilayer perceptron	10,86	24,84	40,58	12,23	23,01
SMOreg	12,44	11,98	14,11	10,22	13,66

Table 9. Mean absolute percentage errors for the five observed market indices, evaluation based on 0,3 training data from 1.2.2015. to 31.1.2020. Base period length is 5 year, bolded values are the lowest values of market indices for certain forecast horizon.

Forecast horizon / Forecasting approach	Market index				
	DAX	Dow Jones	NASDAQ	Nikkei 225	S&P 500
5 days					
Gaussian processes	71,23	80,70	75,73	95,23	49,86
Linear regression	14,03	3,10	8,17	4,21	0,44
Multilayer perceptron	0,66	19,42	5,84	8,20	4,39
SMOreg	6,57	3,53	1,21	2,17	1,69
10 days					
Gaussian processes	119,69	86,24	64,42	124,74	44,66
Linear regression	20,89	5,03	9,60	5,96	0,59
Multilayer perceptron	0,76	22,27	7,42	12,01	5,70
SMOreg	10,08	5,02	2,29	3,40	2,10
15 days					
Gaussian processes	140,47	71,40	53,23	116,90	37,52
Linear regression	25,40	7,06	10,71	8,14	1,22
Multilayer perceptron	1,01	23,07	7,70	13,19	5,65
SMOreg	12,58	5,61	3,71	5,56	2,07
20 days					
Gaussian processes	138,76	72,77	59,48	107,40	41,92
Linear regression	27,21	11,16	14,01	11,71	4,05
Multilayer perceptron	3,40	21,67	6,32	12,20	5,12
SMOreg	12,77	4,76	7,26	9,33	3,81

According to the results from Table 9, when the base period length is reduced to 5 years, SMOreg forecasting approach turned out to be the most precise in most cases through all four observed forecast horizons.

When the base period length is reduced to one year and when 30 % of the training data has been holding out from the end of the series, the results from Table 10 are suggesting that Gaussian processes should be used as the most precise forecasting approach. However, for forecasting DAX the most precise forecasting method turned out to be SMOreg. From the aforementioned results, it can be concluded that machine learning algorithms achieved highly accurate forecasting performance although in some cases the precision could be classified as good forecasting. The exception is the Gaussian processes which showed some incompatibility with data predicted. However, the precision of this algorithm was better for shorter base period lengths and forecast horizons, ie. 1 year base period and 5 days forecast horizon. The precision of all algorithms was expectedly better for shorter base periods and shorter forecast horizons. Furthermore, the precision of all algorithms was much better when all data were included in the analysis concerning the evaluations based only on 0,3 training data. Results obtained from this analysis are in line with other research in this field, machine learning algorithms and neural networks can be characterized as efficient methods for stock market index prediction.

CONCLUSIONS

The goal of the article was to forecast stock market indexes using machine learning algorithms. The results of the analysis have shown that machine learning algorithms achieved highly accurate forecasting performance but in some cases, Gaussian processes specifically, the precision was less than high accurate. This could be explained with the algorithm's incompatibility

Table 10. Mean absolute percentage errors for the five observed market indices, evaluation based on 0,3 training data from 1.2.2019 to 31.1.2020. Base period length is one year, bolded values are the lowest values of market indices for certain forecast horizon.

Forecast horizon / Forecasting approach	Market index				
	DAX	Dow Jones	NASDAQ	Nikkei 225	S&P 500
5 days					
Gaussian processes	3,10	2,31	5,48	0,88	0,67
Linear regression	1,87	4,62	8,02	4,44	6,30
Multilayer perceptron	17,56	3,70	10,21	22,05	10,00
SMOreg	0,96	4,52	7,30	1,01	5,35
10 days					
Gaussian processes	3,22	2,80	6,02	1,19	0,71
Linear regression	3,12	6,16	11,10	6,97	8,43
Multilayer perceptron	21,09	4,48	12,03	24,97	12,50
SMOreg	0,73	6,42	10,53	0,92	7,65
15 days					
Gaussian processes	3,01	3,23	5,38	2,21	1,08
Linear regression	4,32	6,44	12,39	9,93	9,12
Multilayer perceptron	20,10	4,17	12,57	24,88	12,58
SMOreg	0,91	6,98	12,18	2,23	8,60
20 days					
Gaussian processes	3,80	6,23	5,37	4,86	3,91
Linear regression	7,83	5,40	11,20	14,38	7,52
Multilayer perceptron	16,57	4,56	11,04	23,53	10,43
SMOreg	3,72	5,82	11,39	5,27	7,20

with data predicted. The overall precision of all algorithms was better for shorter base period lengths and shorter forecast horizons as well as when all data were included in the analysis regarding the evaluations based on only on 0,3 training data.

Limitations of the article are related to the use of only historical data for the prediction of stock market index values. This is, however, the most common approach in forecasting stock price movements. The use of historical data corresponds to the technical analysis of the stock market. Technical analysis studies historical market data, including prices and volumes in the form of chart patterns and technical indicators. In this article, the fundamental analysis was left out of the framework. Another important limitation of the use of machine learning algorithms for prediction of stock market indexes is in the case of unexpected events or Black swan events such as the spread of COVID-19 when the precision of forecast could not be the most accurate. The achieved performance of machine learning algorithms evaluated in this article could be improved with the inclusion of fundamental analysis as a measure of security's intrinsic value by examining related economic and financial factors. Recommendations for future research could be related to further optimization of algorithms used and investigation of COVID-19 impact on stock market indexes. Stock price prediction remains one of the most complex issues in finance because the factors that influence stock price formation are complex and hard to predict. The optimal prediction method based on machine learning algorithms could help investors in determining their actual best buy-sell strategy and maximizing their profit.

APPENDIX

Table A1. The best forecasting approaches for DAX close daily values, mean absolute error and mean squared error criteria.

Forecast horizon / Base period length	Evaluation of training		Evaluation of held-out training 0,3	
	Mean absolute error	Mean squared error	Mean absolute error	Mean squared error
5 days				
10 years	SMOreg	SMOreg	Linear regression	Linear regression
5 years	Gaussian processes	Gaussian processes	Multilayer perc.	Multilayer perc.
1 year	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
10 days				
10 years	SMOreg	SMOreg	Linear regression	Linear regression
5 years	Gaussian processes	Gaussian processes	Multilayer perc.	Multilayer perc.
1 year	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
15 days				
10 years	SMOreg	SMOreg	Linear regression	Linear regression
5 years	Multilayer perc.	Multilayer perc.	Multilayer perc.	Multilayer perc.
1 year	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
20 days				
10 years	SMOreg	SMOreg	Linear regression	Linear regression
5 years	Multilayer perc.	Multilayer perc.	Multilayer perc.	Multilayer perc.
1 year	Multilayer perc.	Multilayer perc.	SMOreg	Gaussian processes

Table A2. The best forecasting approaches for Dow Jones close daily values, mean absolute error and mean squared error criteria.

Forecast horizon / Base period length	Evaluation of training		Evaluation of held-out training 0,3	
	Mean absolute error	Mean squared error	Mean absolute error	Mean squared error
5 days				
10 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
5 years	Multilayer perc.	Multilayer perc.	Linear regression	Linear regression
1 year	SMOreg	SMOreg	Gaussian processes	Gaussian processes
10 days				
10 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
5 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
1 year	SMOreg	SMOreg	Gaussian processes	Gaussian processes
15 days				
10 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
5 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
1 year	SMOreg	Linear regression	Gaussian processes	Gaussian processes
20 days				
10 years	Linear regression	Linear regression	SMOreg	SMOreg
5 years	Multilayer perc.	SMOreg	SMOreg	SMOreg
1 year	Linear regression	Multilayer perc.	Multilayer perc.	Multilayer perc.

Table A3. The best forecasting approaches for NASDAQ close daily values, mean absolute error and mean squared error criteria.

Forecast horizon / Base period length	Evaluation of training		Evaluation of held-out training 0,3	
	Mean absolute error	Mean squared error	Mean absolute error	Mean squared error
5 days				
10 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
5 years	SMOreg	SMOreg	SMOreg	SMOreg
1 year	Gaussian processes	Gaussian processes	Gaussian processes	Gaussian processes
10 days				
10 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
5 years	SMOreg	SMOreg	SMOreg	SMOreg
1 year	Gaussian processes	Gaussian processes	Gaussian processes	Gaussian processes
15 days				
10 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
5 years	SMOreg	SMOreg	SMOreg	SMOreg
1 year	Gaussian processes	Gaussian processes	Gaussian processes	Gaussian processes
20 days				
10 years	Multilayer perc.	SMOreg	SMOreg	SMOreg
5 years	SMOreg	SMOreg	Multilayer perc.	Multilayer perc.
1 year	Gaussian processes	Multilayer perc.	Gaussian processes	Gaussian processes

Table A4. The best forecasting approaches for Nikkei 225 close daily values, mean absolute error and mean squared error criteria.

Forecast horizon / Base period length	Evaluation of training		Evaluation of held-out training 0,3	
	Mean absolute error	Mean squared error	Mean absolute error	Mean squared error
5 days				
10 years	Multilayer perc.	Multilayer perc.	Linear regression	Linear regression
5 years	SMOreg	SMOreg	SMOreg	SMOreg
1 year	SMOreg	SMOreg	Gaussian processes	Gaussian processes
10 days				
10 years	Multilayer perc.	Multilayer perc.	Linear regression	Linear regression
5 years	SMOreg	SMOreg	SMOreg	SMOreg
1 year	Linear regression	Linear regression	SMOreg	SMOreg
15 days				
10 years	SMOreg	SMOreg	Linear regression	Linear regression
5 years	SMOreg	SMOreg	SMOreg	SMOreg
1 year	Multilayer perc.	Multilayer perc.	Gaussian processes	Gaussian processes
20 days				
10 years	Linear regression	Linear regression	Linear regression	Linear regression
5 years	SMOreg	Linear regression	SMOreg	SMOreg
1 year	Multilayer perc.	Multilayer perc.	Gaussian processes	Gaussian processes

Table A5. The best forecasting approaches for S&P 500 close daily values, mean absolute error and mean squared error criteria.

Forecast horizon / Base period length	Evaluation of training		Evaluation of held-out training 0,3	
	Mean absolute error	Mean squared error	Mean absolute error	Mean squared error
5 days				
10 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
5 years	Gaussian processes	Gaussian processes	Linear regression	Linear regression
1 year	Gaussian processes	Gaussian processes	Gaussian processes	Gaussian processes
10 days				
10 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
5 years	Gaussian processes	Gaussian processes	Linear regression	Linear regression
1 year	Gaussian processes	Gaussian processes	Gaussian processes	Gaussian processes
15 days				
10 years	Multilayer perc.	Multilayer perc.	SMOreg	SMOreg
5 years	Gaussian processes	Gaussian processes	Linear regression	Linear regression
1 year	Gaussian processes	Linear regression	Gaussian processes	Gaussian processes
20 days				
10 years	Multilayer perc.	SMOreg	SMOreg	SMOreg
5 years	Gaussian processes	SMOreg	SMOreg	SMOreg
1 year	Multilayer perc.	Multilayer perc.	Gaussian processes	Gaussian processes

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IMPROVING STRUCTURAL DESIGN OF SOFT ACTUATORS USING FINITE ELEMENT METHOD ANALYSIS

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DOI: 10.7906/indecs.18.4.8
Regular article

Received: 29 June 2020.
Accepted: 23 September 2020.

ABSTRACT

The latest progress in robotics includes the development of so-called soft robots. When it comes to actuation, most of the research in this field is strictly experimental, meaning that performance is observed *a posteriori*, on previously manufactured specimens. Although significant, results are often incidental and without a proper understanding of how the structure dictates properties of the soft robot. In this article, we propose a parametric modelling procedure of pneumatic soft actuator, in particular the Bellows-type actuator. Finite element method is used to analyse responses of the actuator to different topological changes in the structure. The initial structure of the actuator is represented with a set of parameters upon which simulation is performed. Results of these simulations give us insight into the nature of parameters, revealing which changes are desirable and which are not, depending on the different objectives set. By combining different parameters, the structure is improved in the sense of bending capability while stress in the material is even reduced. Particular attention was paid to the material modelling to achieve realistic results in the simulations.

KEY WORDS

soft robots, design, optimization, FEM analysis, 3D printing

CLASSIFICATION

ACM: B.4.2
JEL: Z00

INTRODUCTION

Soft robotics is a growing field that focus on constructing robots out of soft materials. The term soft refers to materials that share similar stiffness as materials found in natural organisms. While traditional robots are made of hard materials such as metals, with Young's modulus in a range of 10^9 - 10^{12} Pa, biological materials such as skin and muscles have Young's modulus of much lower magnitude, typically around 10^4 - 10^9 Pa [1]. Engineering materials such as silicones, rubber, hydrogels etc. fit well into this range which makes them considered as soft materials and capable for use in soft robotics. Today, additive technologies are advantageously used to manufacture very complex designs with unintuitive mechanical properties [2, 3].

Using materials with low stiffness means that they will be subjected to large strains during use. In case of soft robots, this property is desirable because it enables different applications such as grasping [4, 5], locomotion [6-9], and sensing [10-12]. Unlike conventional robots which are functional only in highly defined environment, soft robots provide much more flexibility when it comes to grasping objects. They conform to the shape, excluding possibility of concentrated pressure that can damage object which makes them safe for grasping soft and sensitive objects as well as objects which shape is originally unknown. Large deformations and ability to adapt brings to conclusion that soft robots can achieve theoretically infinite degrees of freedom with only one input [13].

Compatibility in stiffness between soft and natural materials makes them able to resemble movements of natural organisms. This property is highly exploited in the field of biomimetics where soft robots proved successful to mimic locomotion of various animals, e.g.: fish [6], worm [7], snake [8], octopus [9], artificial muscles [14] etc. These extraordinary movements require new sensors that can follow the large deformations of a soft body. A breakthrough in this field is already made with so called soft sensors [10, 12]. Absence of rigid component makes soft robots inherently safe for interactions with humans. In the area of medical robotics, soft robots are used for wearable devices that improve rehabilitation process for patients with musculoskeletal diseases such as arthritis, cerebral palsy, Parkinson's disease, and stroke [15, 16]. Continuum kinematics and ability to navigate through narrow spaces without damaging the surrounding environment makes them ideal candidates for minimally invasive surgery, particularly in the field of endoscopy [17]. Appropriate control algorithms for efficient path planning of such robots, when sharing environment with other moveable objects, should be developed and tested, similarly to the classical robotic field [18-20]. Additionally, there is a lack of formal modelling of in soft robotic literature, although some important findings have been made recently [21-25].

Soft robots can be actuated in many different ways: using cables or shape memory alloys [26, 27], electrically using electroactive polymers [28] or pressure driven, using pneumatics [12, 29, 30], or hydraulics [31]. Although there are many different types within family of soft pneumatic actuators [32], we focus on Bellows-type [5] of soft pneumatic networks. The structure of these actuators is made out of connected chambers which, once subjected to pressure, result in bending of entire actuator. Small chambers require less volume and less pressure for actuation, making them fast and efficient [33]. When compared to tube shaped actuators, Bellows type experience lower strain which suits them better for less flexible materials such as TPU. Since the whole structure is modular, by selective actuating of single cells, specific motions can be achieved. Bellow type of actuators consist of only one part which makes them suitable for 3D printing or casting.

Despite large popularity of research in the field of soft pneumatic actuators, very few of them are occupied with strictly formal modelling. Unlike conventional robots whose links are of

correct form, structure of soft robots is often too complex to be expressed by mathematical equations, so different approach must be chosen. Additional problems arise because of highly nonlinear material behaviour and large strains. In this article we present a procedure for improving structure of Bellows-type of soft pneumatic actuators, using finite element analysis (FEA).

MATERIALS AND MODELLING

Soft pneumatic networks are usually made out of two materials: silicone rubber and thermoplastic polyurethane (TPU). The first one shows more flexibility and is more often used as material for pneumatic actuators but can be fabricated only by casting. Since we plan to use direct 3D printing process, we will rely on TPU. This material belongs to the class of thermoplastic elastomers that shares both thermoplastic and elastomeric properties. Combination of properties gives them ability to be stretched to moderate elongations and at the same time to be processed by melting. From many available TPU filaments, we have chosen to use NinjaFlex because it is most widely known and commercially available. As it can be seen from Table 1, it offers great flexibility and tensile strength. [34].

Table 1. Basic mechanical parameter for NinjaFlex filament, given by the manufacturer.

Mechanical property	Value
Yield strength	4MPa
Youngs modulus	12MPa
Tensile strength, ultimate	26MPa
Elongation at break	660 %

We begin improving process with designing initial structure.

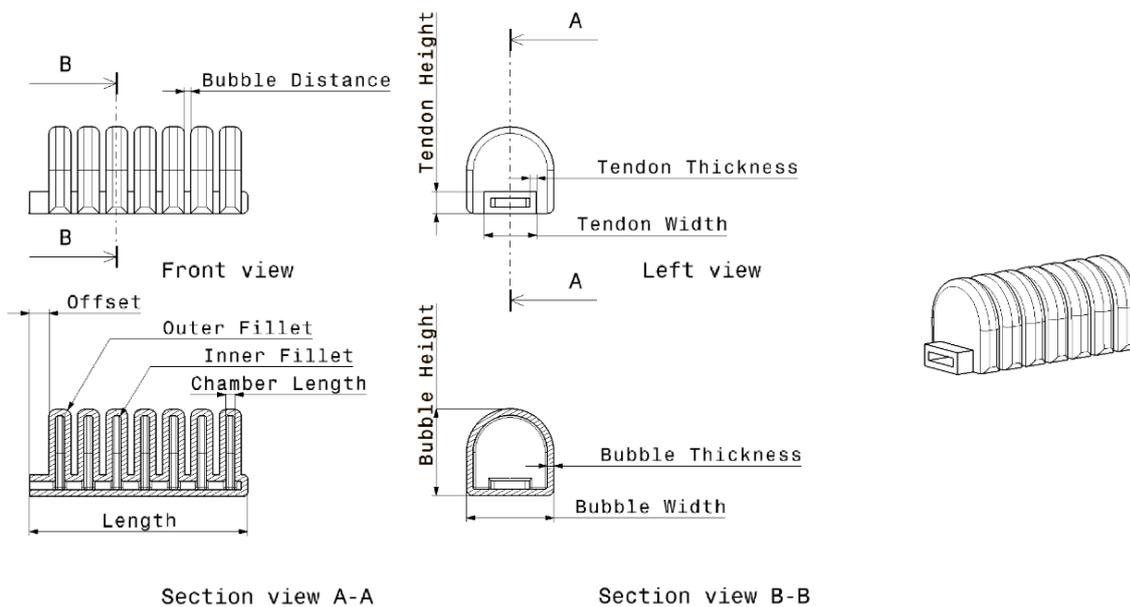


Figure 1. Testing structure.

Three requirements have been chosen for design of actuator: (1) it should withstand maximum pressure of 1 bar, (2) maximum stress should not be higher than yield strength of material which is 4MPa, (3) cross section should not exceed 20x20 mm. This last requirement is added so that dimension of actuator approximately fit dimensions of human finger. The 3D model is made in CATIA using parametric design which allows instantaneous redefinition of complete structure with change of a single parameter. Initial design is displayed in Figure 1. Entire structure can be described with a total of 12 parameters whose initial value are given in Table 2.

Length and Offset are not meant to be changed while other 10 parameters will be, one by one, subjected to FEM analysis.

For any kind of structural analysis, it is necessary to have an accurate material model. In the most basic form, it implies knowing relations between stress and strain. Most common engineering materials such as metals show linear elasticity below yield strength which makes them easy to model according to Hooke's law, using only Young modulus as a parameter.

Table 2. Prototype values: 1- Initial structure; 2 – Improved structure.

Parameter	Prototype 1 [mm]	Prototype 2 [mm]
Bubble Width	20	20
Bubble Height	20	20
Bubble Thickness	1,5	1,2
Tendon Width	12	6
Tendon Height	5	6
Tendon Thickness	1,5	1,6
Chamber Length	2	6
Bubble Distance	1,5	1,6
Inner Fillet	0,5	0,7
Outer Fillet	1,5	1,9
Length	50	50
Offset	5	5

On the other hand, rubberlike materials, such as TPU belong to the class of hyperelastic materials which exhibit nonlinear stress-strain behaviour even in the zone below yield strength. In this case Youngs modulus can be relevant only for near-zero values of stress and strain and since we aim to achieve large deformations, it cannot apply. Furthermore, there are numerous factors that affect properties of polymers, such as molecular weight, processing, etc. meaning that same material can have differing properties within different manufacturers. For this reasons, only reliable way to determine needed relations between stress and strain is to obtain them as a result of tensile testing for exact material. Most filament manufacturers do not offer this data and situation is no different for NinjaFlex. Luckily, a work of T. Reppel and K. Weinberg [35] is all about determining stress-strain relations of a 3D printed NinjaFlex so we will use data from their experiments.

Defining a hyperelastic material in Abaqus can be done in two ways. First, by entering table data of tensile tests. Up to 4 different test data can be entered: uniaxial, biaxial, planar and volumetric. For an incompressible isotropic material, uniaxial test data is often enough to get decent results, although Abaqus documentation recommends combining multiple tests for better accuracy [36]. Secondly, by setting a strain energy density function with necessary parameters. User can select between several different formulations but we focus on Ogden model since it generates the best fit [35, 37].

Ogden model is a function that describes nonlinear stress-strain behaviour of rubberlike solids. Essentially it is a compact way to approximate results obtained from uniaxial test, using only couple of parameters that define material. Since we do not have tensile test data at disposal, for our simulation, we will use parameters that T. Reppel and K. Weinberg calculated in [35]. Nevertheless, for completeness of this article, procedure of acquiring these parameters is described in following section.

Ogden's formulation express strain energy density W in terms of principal stretches λ_j ; $j = 1, 2, 3$.

$$W(\lambda_1, \lambda_2, \lambda_3) = \sum_{p=1}^N \frac{\mu_p}{\alpha_p} (\lambda_1^{\alpha_p} + \lambda_2^{\alpha_p} + \lambda_3^{\alpha_p} - 3). \quad (1)$$

where W represents strain energy density, N represents strain energy order while μ_p and α_p are material parameters. Next step is to make reasonable assumptions that will simplify (1). Rubberlike materials experience very little compressibility compared to their shear flexibility so in applications where material is not highly confined to small spaces, assumption of incompressibility gives satisfactory results [36]. For incompressible materials, constraint (2) must be satisfied.

$$\lambda_1 \lambda_2 \lambda_3 = 1. \quad (2)$$

Although rubberlike materials generally show isotropic properties, because of our production method, 3D printing, one has to be careful. As it is shown in [37], using diagonal infill with one line of shell brings us close to isotropic properties. Under assumption of isotropic material and uniaxial tensile stress, principal stretches can be expressed as:

$$\lambda_1 = \lambda, \lambda_2 = \lambda_3. \quad (3)$$

From (2) and (3) we get relation between stretches:

$$\lambda_2 = \lambda_3 = \lambda^{-\frac{1}{2}}. \quad (4)$$

Inserting (4) into (1) gives us Ogden model for incompressible isotropic material under uniaxial stress:

$$W(\lambda) = \sum_{p=1}^N \frac{\mu_p}{\alpha_p} \left(\lambda^{\alpha_p} + 2\lambda^{-\frac{1}{2}\alpha_p} + \lambda_3^{\alpha_p} - 3 \right). \quad (5)$$

Finally, partial derivation of stain energy density with respect to stretch give us stress strain relation for uniaxial case [26]:

$$\sigma_1 = \sum_{p=1}^N \mu_p \left(\lambda^{\alpha_p-1} - \lambda^{-\frac{1}{2}\alpha_p-1} \right). \quad (6)$$

By combining test data, (6) and numerical algorithms for curve fitting we can derive constants μ_p and α_p of hyperelastic material. Usual practice is to start curve fitting with strain energy order $N = 1$ and gradually rise it if results are not satisfactory. Hill's criterion should apply to ensure material stability [38]:

$$\lambda_p \alpha_p > 0, \forall p = 1, \dots, N. \quad (7)$$

Ogden model in Abaqus is defined slightly different than (1) so after calculating μ_p and α_p , adjustment needs to be made.

$$\mu = \frac{\mu_p \alpha_p}{2}. \quad (8)$$

In the simulations presented in this article, we used second order Ogden with parameters as given in Table 3. Parameters D_1 and D_2 are left 0 for incompressible materials [36]. Resulting stress-strain curve is shown on Figure 2.

Table 3. Parameters for Ogden model of NinjaFlex, as defined in Abaqus.

μ_1 , Pa	α_1	μ_2 , Pa	α_2	D_1	D_2
198 250	3,05	3 277 800	-0,0054	0	0

Due to high strains, “geometrically nonlinear analyses” option must be selected in Abaqus. Meshing is performed using quadratic tetrahedral hybrid elements (C3D10H). Hybrid formulation is recommended for incompressible or close to incompressible materials. Seed size is set to 1mm and lowered if needed, ensuring that there is always two layers of elements along structure walls. Above setting typically generated around 50 000 elements. Every model was subjected to pressure of 1 bar.

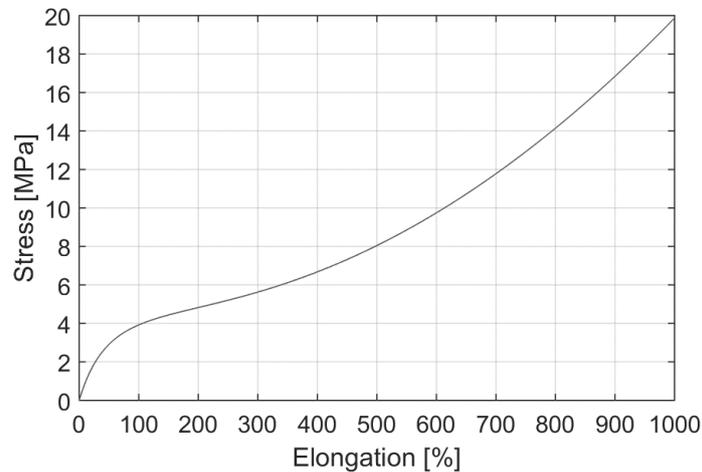


Figure 2. Stress-Strain curve for NinjaFlex, as a result of parameters from Table 3.

RESULTS AND CONCLUSIONS

With respect of material and above-mentioned settings, FEM analysis was performed 11 times. First, to get result for Prototype 1 which serves as a reference, and then for every other parameter separately. Changing only one parameter at the time allows us to observe its impact on the structure. Two features were measured – maximum stress in the volume, and bending angle of the whole structure. Increase in bending angle is considered positive change while increase of maximum stress is considered negative. These values for the Prototype 1 are: Bending angle: 220°, and Maximum stress is 4.547 MPa., Results of the initial simulation and parametric study are illustrated on Figure 3.

From Table 4 we can observe that some parameters have strong influence while others are less significant. Usually positive impact on one feature follows negative impact on other but there are also features that have both positive and both negative impacts.

Table 4. Impact of parameters and comparison with Prototype 1.

Parameter	Initial Value, mm	Tested value, mm	Bending angle	Max. Stress, MPa
Bubble Width	20	16	100° (-54,3 %)	3,150 (-30,7 %)
Bubble Height	20	16	175° (-20,5 %)	4,142 (-8,9 %)
Bubble Thickness	1,5	1,2	335° (+52,3 %)	5,211 (+14,6 %)
Chamber Length	2	1,2	240° (+9,1 %)	4,720 (+3,8 %)
Bubble Distance	1,5	1	230° (+4,5 %)	4,544 (-0,1 %)
Tendon Width	12	6	290° (+31,8 %)	3,607 (-20,7 %)
Tendon Height	5	4	230° (+4,5 %)	4,713 (+3,7 %)
Tendon Thickness	1,5	1,2	230° (+4,5 %)	5,678 (+24,9 %)
Inner Fillet	0,5	1	200° (-9,1 %)	2,742 (-39,7 %)
Outer Fillet	1,5	2	220° (+0,0 %)	4,530 (-0,4 %)

More often is that one parameter has bigger impact (positive or negative) on one feature and less on the other. Idea is to always choose properties that have more pronounced positive impact.

From what we learned in Table 4, a new set of parameters is defined (Table 2, Column 3 – Prototype 2. Reducing Bubble Width and Bubble Height proved to have a strong negative effect on bending angle while decrease in stress less notable. Increasing these dimensions could make an opposite effect but because of our requirement on the cross section, these dimensions remained the same. Reducing Bubble Thickness has major impact on increase of bending angle so this value is reduced to 1,2 mm which is a theoretical minimum bounded by the nozzle

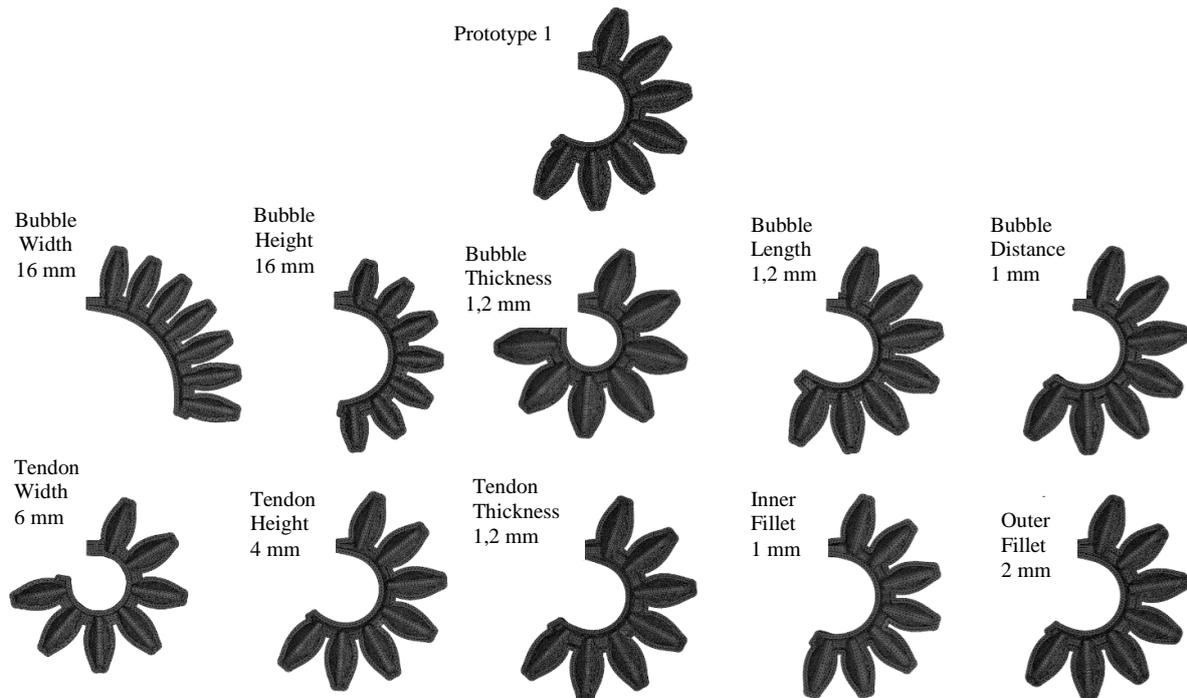


Figure 3. Results of FEM analysis: Prototype 1 compared to a set of design modifications.

diameter, of the 3D printer used (Prusa I3). Since we plan to use 3D printer, we have to think about layers when deciding about the thickness property. According to [39], thickness should be in multiples of the nozzle size and there should be at least three layers to ensure airtightness. Since we plan to use 0,4 mm nozzle, we will stick to values of 1,2 mm and 1,6 mm when choosing thickness property. Dimensions that are longitudinal, Chamber Length and Bubble Distance do not have strong effects so they are decreased in order to fit another two bubbles on the structure. Higher density of bubbles will increase the bending angle. Decreasing Tendon Width has the most positive impact of all properties – at the same time it increases bending angle and decreases maximum stress. Since we decreased it to 6 mm, we increased Tendon Height, whose impact is insignificant, to ensure good air flow. Reducing Tendon Thickness proved to increase stress in material so to achieve an opposite effect we increased this value to 1,6 mm. Increase of Inner Fillet has the strongest impact on reducing stress so it is set to the maximum value – half of the chamber length.

After FEM analysis was run for Prototype 2, we can observe large increase of bending angle. Overlap is allowed to measure this increase. Bending angle increased almost double: +90,9 % while stress is lowered for -13,2 %.

By observing a detail view, Figure 4, we noticed that maximum stress values are always concentrated on the bottom wall, underneath the chamber. This is also a point where largest

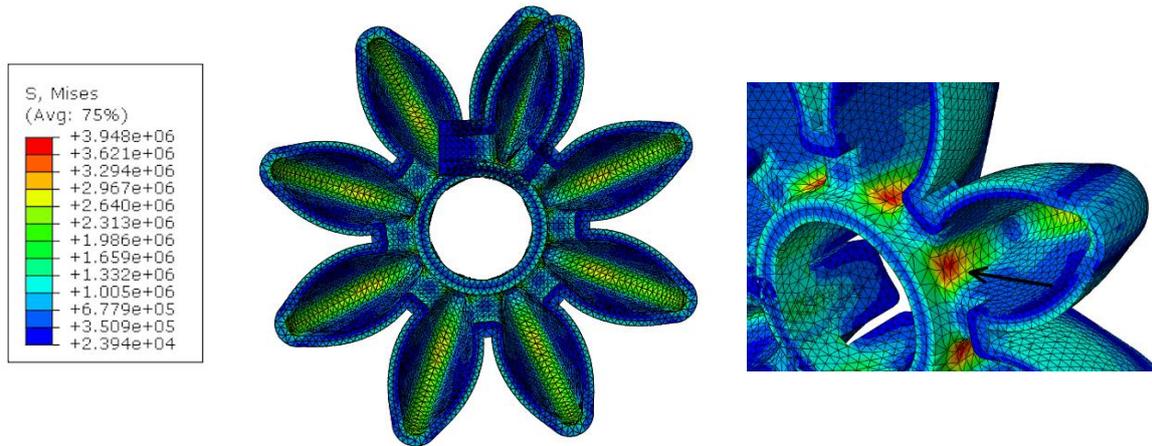


Figure 4. FEM analysis for parameters from Table 2, Prototype 2. Detail view on right, arrow pointing to an area with maximum stress in material.

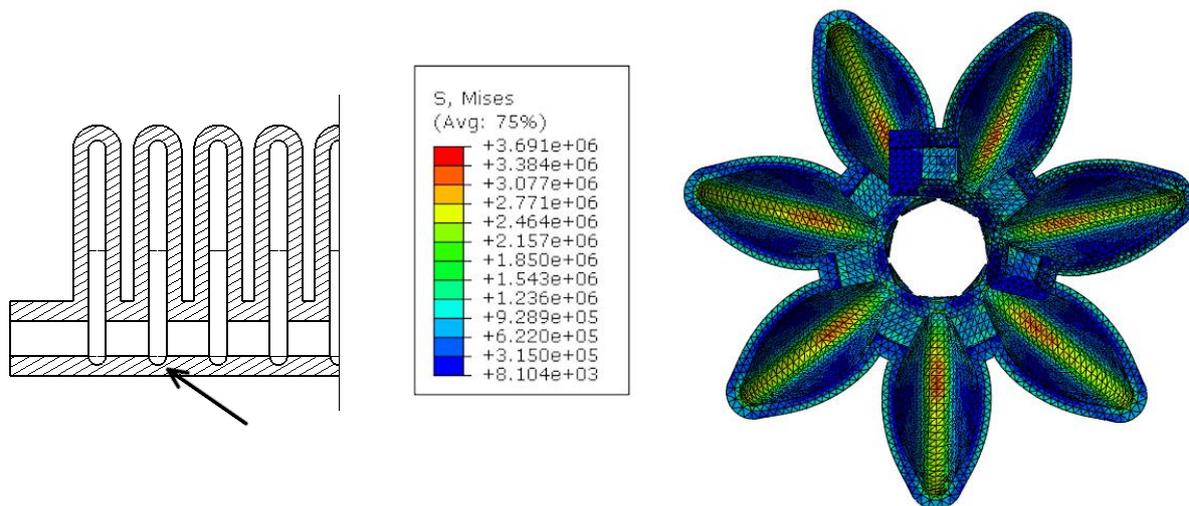


Figure 5. Small indent as a final improvement and results from FEM analysis.

strains are expected and consequently a point where structure will break most likely. By removing material from this point, structure is able to bend more freely resulting in lower strains.

As it can be seen on Figure 5, making an indent on the place of maximum stress improved our structure even more. When compared to Prototype 1, bending angle is increased by +113,6 % while stress is lowered by -18,8 %.

Final confirmation of the approach presented in the study will be upon conduction a thorough experimental validation for the specimens proposed. In this article, the authors have tried to give important aspects to consider when trying to improve the structure of a soft actuator based on the Bellows structure. Some of the correlations between different parameters and their impact to the actuators' behaviour are revealed. It would be interesting to formally describe the dependency between the parameters and the response of the actuator, in order to reveal the nature of different parameters. This requires additional experimental validation and will be included in our future research. and These actuators are becoming largely present in mainstream robotics and will be even more in the future, so insight in their structural properties is essential.

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SINGLE RIGID LADDER SAFETY REVISION AFFECTED BY ASCENT BIOMECHANICS

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DOI: 10.7906/indecs.18.4.9
Regular article

Received: 28 September 2020.
Accepted: 21 October 2020.

ABSTRACT

The objective of this article is to review the critical conditions of a single beam ladder using the temporospatial ladder stability analysis with integrated biomechanical considerations. From the ergonomic perspective, the non-occupational incidents may involve even more critical parameters than the occupational incidents. This is because the occupational users are assumed to have necessary psychophysical abilities, experience, training and awareness of appropriate standards and regulations, and are moreover familiar with proper ladder settings and their utilization, unlike most of the non-occupational users. Such a perspective supports our safety concern about ladder use, especially for non-occupational environments, what is in focus of this article.

Computational modelling of expected ladder ascent and usage were exploited, with taking into consideration the real time kinetics and kinematics, anthropometry of the climber and variable contact friction factors. The results are shown in a parametric diagram, that revises and confirms the guideline for setting the ladder slant at 75,5°. Then, regardless of the climber's mass, the intensity of the ascent (period or cycle duration, hence the extremes in acceleration), and of the low coefficient of friction at the ground contact, the climb is safe.

Created computational ladder model and representative equations are validated, henceforth the created computational model is attributed the ability to revise the ladder use recommendations. Created and validated model is expected to makes possible a further extension of the set of the considered and analysed ladder usage parameters. Hence, inclusivity of wider range of parameters of ladder utilization and design is expected to reveal other underestimated or neglected factors that might appear as critical ones.

KEY WORDS

single ladder, ladder climbing, ergonomic and biomechanical parameters, safety against sliding, safety against separation, ladder stability

CLASSIFICATION

JEL: I12, I18

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INTRODUCTION

A single ladder, is as reported by many scientists, hazardous equipment for extending the human reach. Various ladder use incidents and consequently injuries occur in both environments, occupational and non-occupational [1, 2], which is unfortunately, still the case. Among other findings is that sliding and cross section buckling are the main cause of ladder injuries, and most of available reported data/occurrence of ladder incidents and their consequences are about occupational incidents, but lacking to provide data for non-occupational incidents and consequent injuries. It was reported [3] that in 2005 in the USA 20 000 workers were injured and over 100 died as a result of falls from ladders. Another report [4] mention that in the USA in 2012 cost burden was 5,12 billion US dollars due to workers falls to lower level, which includes falls from ladders, and that ladder incidents persist to be major concern, despite improved standards and regulations. There are many different sources that confirm these statements and reports every year, but similar reports are not available worldwide to enable systematic problem overview, especially for non-occupational environments. Another possible restriction is that there are various types of ladder design that also may have its own ladder incidents reasoning, and may not have common causality for every ladder type in general.

Another set of data not reported about ladder incidents are circumstances and environmental parameters, user's age and personal psychophysical condition, experience, anthropometry, type of task performed and climbing technique, possible disturbances and so forth including true causes of reported incidents occurrence. Speculation about analysis of ladder use parameters (with respect to ladder purpose – a tool/equipment) that will reveal critical issues can be continued, but instead, our focus is on ladder usage model consisted of man, ladder, and environment. Each sub-element of this model has its own parameters that should be taken into consideration.

From ergonomic perspective, non-occupational incidents may involve even more critical parameters than in occupational incidents since occupational users are assumed to have necessary psychophysical abilities, experience, training and awareness of appropriate standards and regulations and are familiar with proper ladder settings and their utilization, unlike most non-occupational users. Such perspective supports our safety concern about ladder use, especially for non-occupational environments, that is in focus in this article. Hence, safe ladder utilization implies various parameters to be properly applied during user ladder ascent and descent, and of course, task completion.

Many scientists have investigated how climbers (workers) set up the ladder, in context of the recommended inclination angle of $75,5^\circ$. Average angle achieved in real life situations is below $75,5^\circ$, mostly around 70° . In 49 % of straight ladder incidents, the inclined angle was less than 65° [5].

Articles concerning the ladder climbing safety report dynamics of climbing measured by a dynamometer, some kind of scales [1, 6], or with Inertial Measurement Unit (IMU) supported analysis [7]. IMU supported analysis [7] considered aspects of biomechanical analysis during ladder ascent with objective to identify musculoskeletal stresses that might explain possible risks and hazards. Numerically addressed ladder problem [8] considered taking into account physics and mechanical modelling of ladder behaviour, however, other elements of the system were neglected. Further, [9] analysed effects of aerial ladder rung spacing on firefighter climbing biomechanics, with conclusion that reduced rung spacing may lead to lower biomechanical stress, better climbing efficiency and safety and reduced climbing speed disparity across sexes. Such finding connects anthropometrical data with ladder design that

opened speculation about optimal relation – what is the best fit of the man to the task, and consequently, the ladder design. From systematized gathered findings with preceding researches [9] can be recognized that most of the reports are about occupational environments and ladder utilization.

Comprehension of hazards related to ladder use implies that specific variables exist in the ladder use that can be identified as critical – that affects safety, where other parameters of the user-ladder system may be considered as variables that vary the utilization efficacy. Anyhow, all-inclusive policy should be supported, with regard to safety of all potential users. It is obvious that ladder stability is the first priority to be achieved, that can be compromised by ascent dynamics, ladder setup/slant and its design, beside other environmental and utilization conditions. Regarding ladder stability, it is comprehended as dynamics of ladder behaviour throughout its utilization where ladder ground contact support forces remain within acceptable margins, along with absence of ladder rotation (which may be caused by or can cause sliding movement – frontal or/and sagittal), with appropriate structural integrity. However, although stability priority covers issues with structural integrity as another important perspective of the problem, it is not within the scope of this article.

This article will address non-occupational users and ladder design utilization, where numerical modelling will be employed. Objective is to review critical conditions of ladder use by temporospatial ladder stability analysis when biomechanical considerations are also integrated – with respect to human body kinematics and dynamics. In viewing the ascent on single ladder as a rigid body, or construction, available references do not report sagittal climber's centre of mass trajectory in correlation with a function of time, ascent dynamics nor their impact on ladder stability, which was consider that matters. Expected ladder ascent and use of computational modelling results should reveal true ergonomic and biomechanical challenges, safety adjustments and revise available recommendations for potential ladder user, both occupational and non-occupational. Such contribution will enable proper ladder design, structural analysis and consequently will advance ladder use in order to contribute to better safety of use, lesser accidents occurrence and fatal consequences.

METHODS AND MATERIALS

As defined earlier, single ladder use model is considered to be composed of a person (who will climb the ladder to extend his reach), ladder (its design and specifications), and environment (ground and vertical wall, as physical contacts of slant ladder).

LADDER MODEL

A single ladder hereon denoted as a rigid body, is designed with two longitudinal main beams connected with step beams (transverse beams), rungs. Main beams can be set so that their transverse distance is constant, or decreasing along the longitudinal ladder axis, in ascent direction. It is assumed that single ladder will be positioned on the firm ground and inclined toward vertical wall. Ladder position is considered to achieve symmetrical contacts with respect to ladder longitudinal axis – there is no lateral inclination (at least in this article). Hence, central sagittal ladder plane is used as reference plane. Ladder slant angle is determined as angle achieved between ladder longitudinal axis and the horizontal ground plane in the central sagittal plane, in literature also defined as inclination angle between ladder axis and the ground/floor plane.

Since one of the objectives was to revise non-occupational parameters of ladder use, commercially available single aluminium ladder were taken as geometric model for computation. The ladder's mass is 14,2 kg, actual rung spacing is 0,28 m (11 in) and total

ladder length is 5 m (16 ft. 5 in). Rung distance and ladder width are fixed. Moreover, created ladder model should enable adjustments of rung distance, and can be used for analysis of ladders with parallel and non-parallel main beams.

LADDER CLIMB STYLE

The base for calculating climber's centre of gravity (CoG) and its biomechanics is the climbing style, which implies maintenance of a 3 point contact during each step that is presumed to be completed with identical kinematics. Ladder climbing requires full body coordination to maintain points of contact using both upper body and lower body. Previous research has indicated an overlap between hand contact and foot contact with the ladder [1, 3]. Assumption that central sagittal plane (CSP) is the plane of climbers CoG trajectory has been embraced since if movement trajectories of arms and legs remain in sagittal planes approximate to the CSP, CoG will be most distant from ladder longitudinal axis, which is recognized as the most unfavourable case of movement along the ladder. Moreover, even if that would not be the case, most of the CoG motion will still remain close to CSP, hence lateral climb perspective represents most appropriate presentation of climbing activities, depicted in Figure 1.

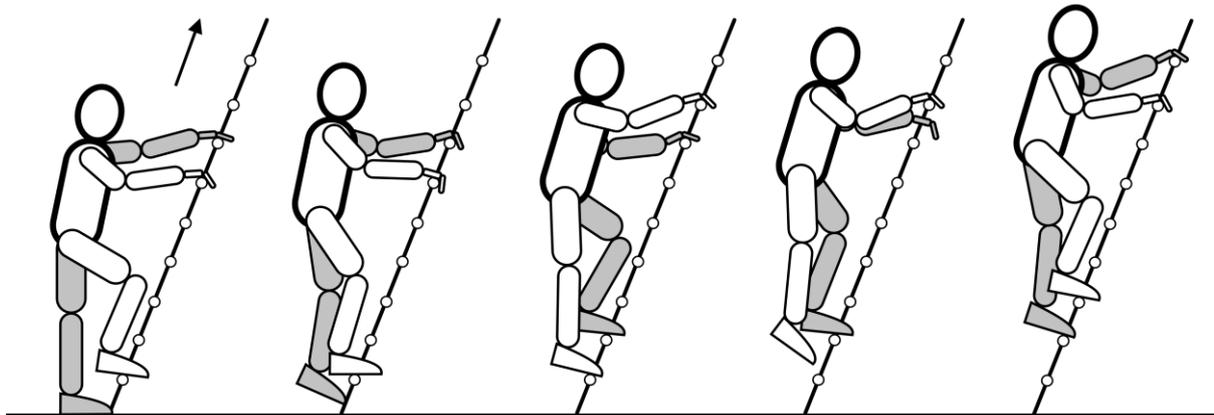


Figure 1. Few steps of a person climbing a single ladder.

Ladder ascent is defined as a process starting from the resting stand, followed by acceleration, deceleration and stopping with resultant displacement of the body CoG along the length of the ladder for a single rung. Ascent is discretized in 10 steps, i.e. positions. Resting stand assumes one leg extended, while other leg rests on the first subsequent rung and with hands grasping the rungs at appropriate level.

For the purpose of biomechanical modelling of ladder climb, the human body movements have been represented by CoG trajectory (Figure 2a) that is calculated for each discretized step, with respect to climber body segments position throughout the process of analysed climbing, using reported methodology for calculating CoG [10-12].

In the following calculation a climber height as 1,7 m and variable body mass is being considered. The authors themselves have verified that climber's height of 1,7 m leads to arms – legs span (distance from middle of hands grasping rungs and middle of feet leaning rungs with given rung spacing in climb) of 1,4 m (4 ft. 7 in). The climber's mass has been normalized to a 50th percentile of males average mass of age 20 and above in USA [13]. Based on the calculated trajectory, CoG is then approximated by a function of time to serve for calculating dynamics at any desired position, i.e. time in the ascent cycle.

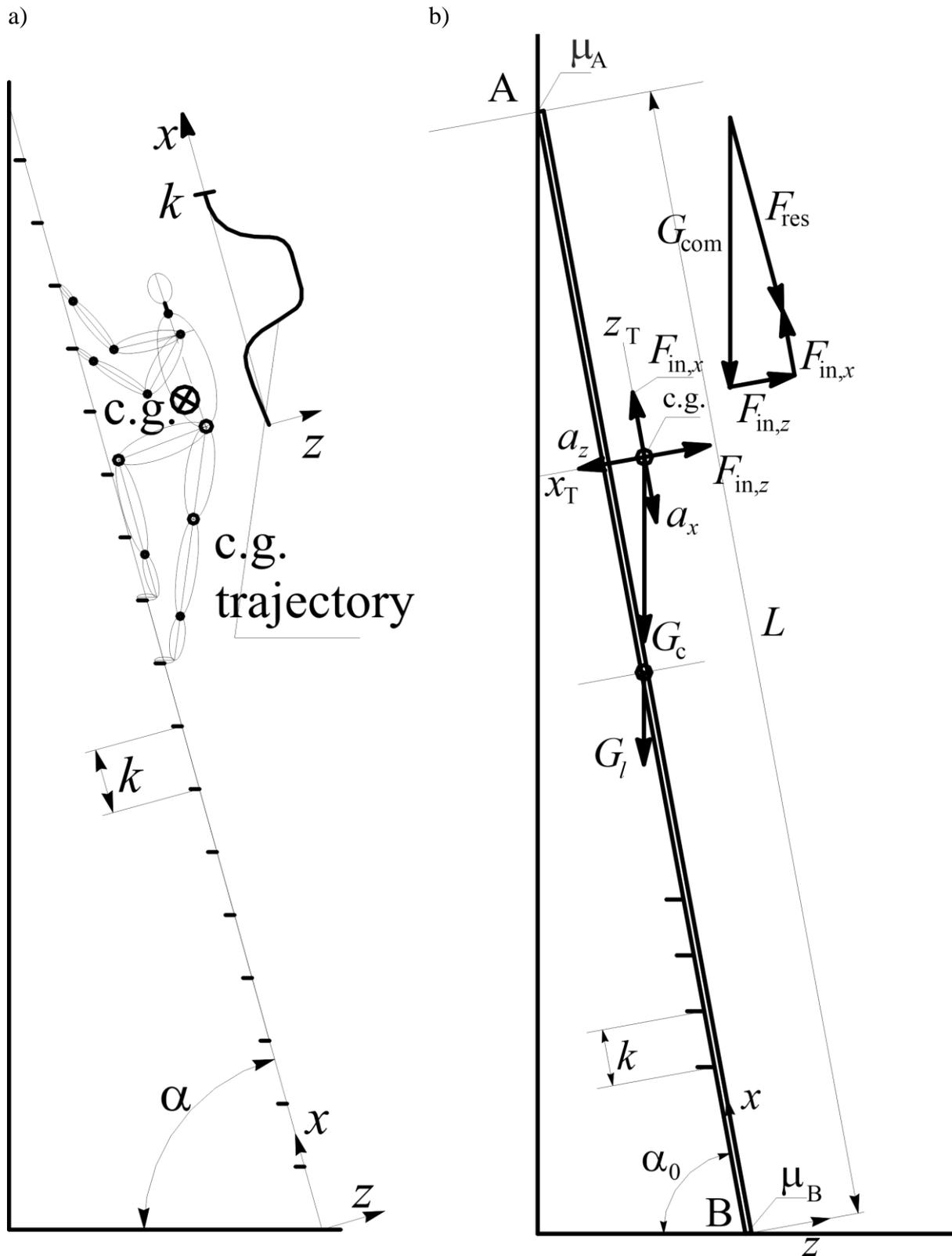


Figure 2. A person climbing the ladder [12]: a) kinematics, b) dynamics – loads, c) force polygon, d) separation from the wall problem and e) sliding on the floor problem (continued on pp.506-507).

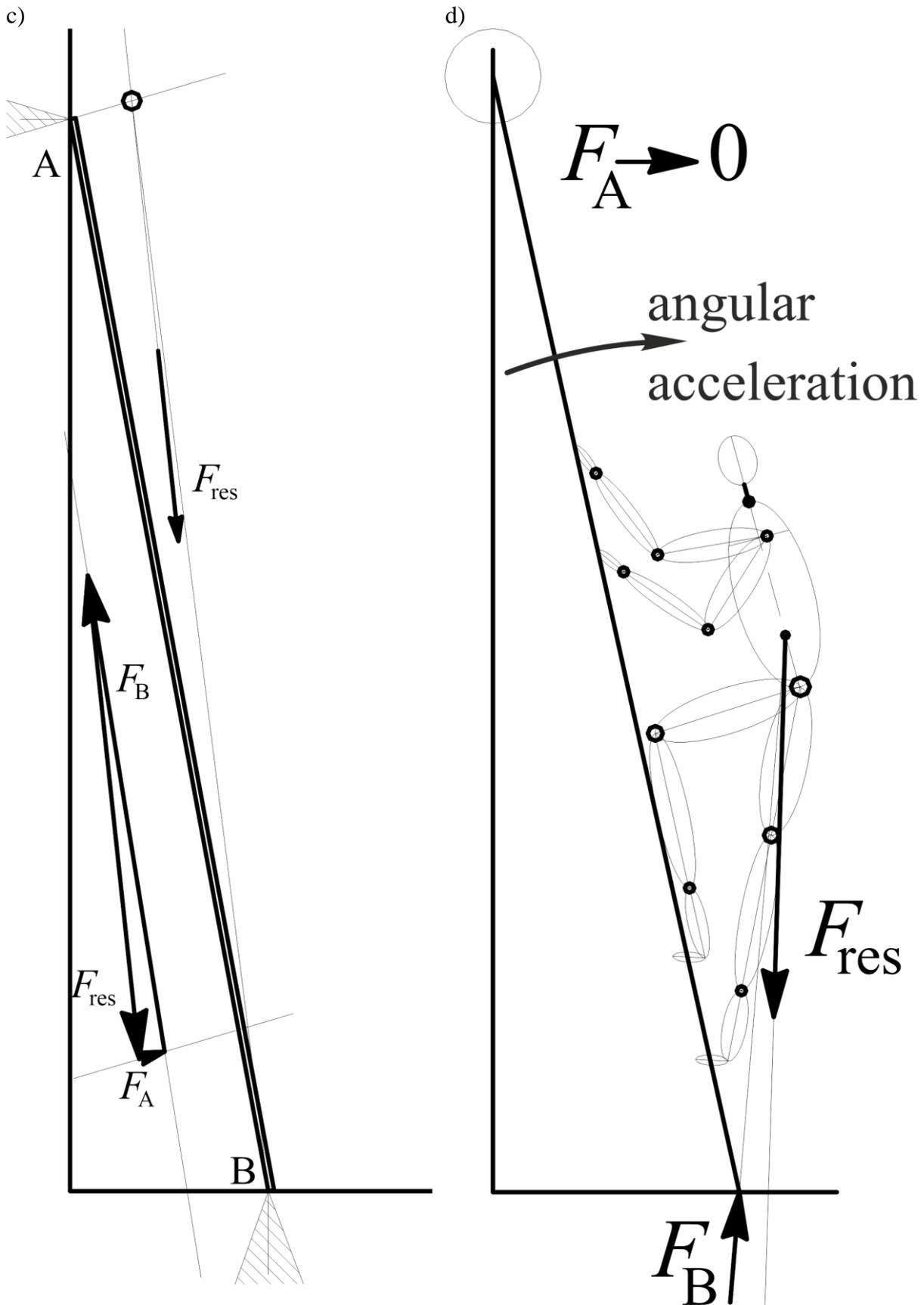


Figure 2. A person climbing the ladder [12]: a) kinematics, b) dynamics – loads, c) force polygon, d) separation from the wall problem and e) sliding on the floor problem (continuation from p.505, continued on p.507).

e)

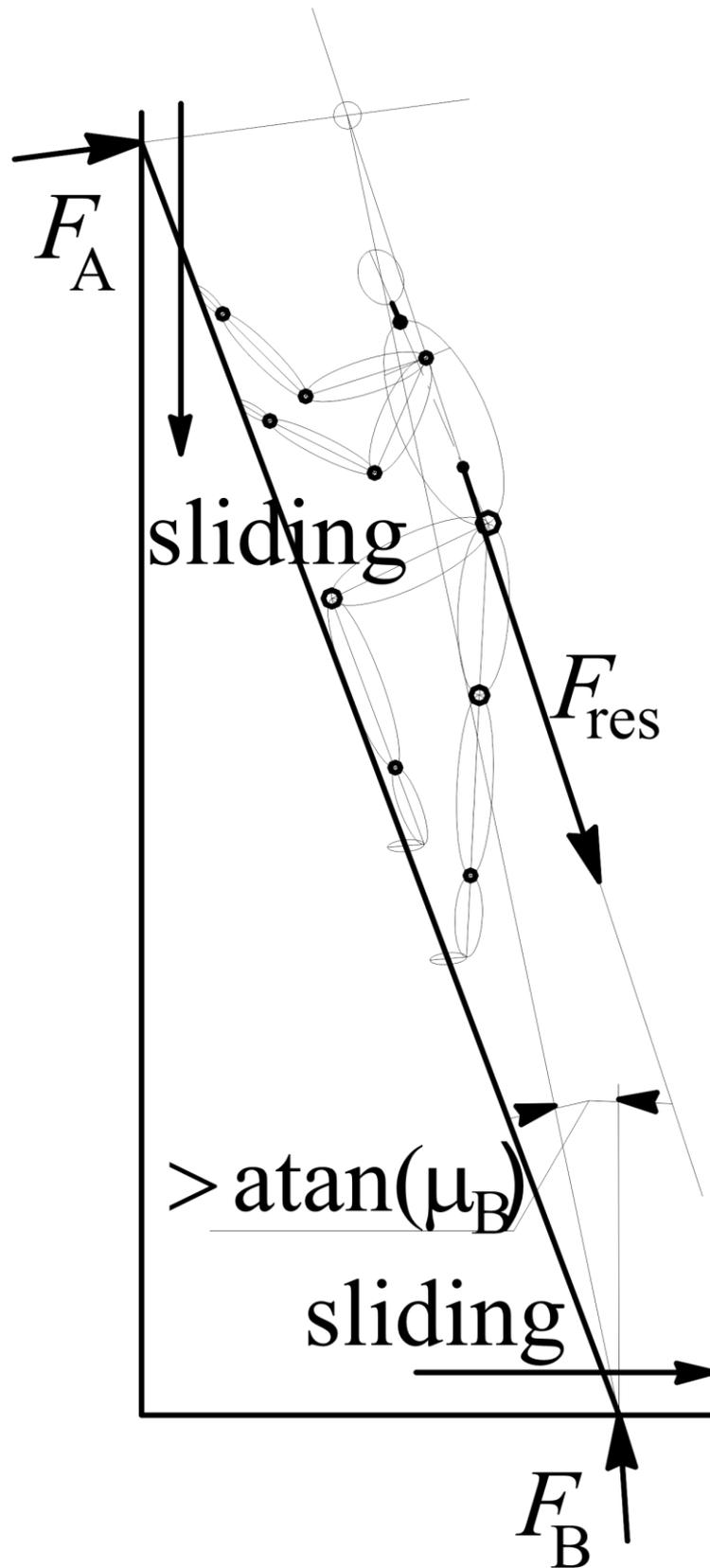


Figure 2. A person climbing the ladder [12]: a) kinematics, b) dynamics – loads, c) force polygon, d) separation from the wall problem and e) sliding on the floor problem (continuation from pp.505-506).

ASCENT HUMAN BODY KINEMATICS AND DYNAMICS

Kinematics is defined with the calculated CoG and adopted climbing cycle duration [3, 14] with suggested duration of mild and intensive climbing cycle to be 1,5 s and 1,0 s, respectively. With that information, the kinematics in components on coordinate axes x and z (along and perpendicular to the ladder, respectfully) is described with interpolating polynomials by parts of ascent cycle (as will be described latter) as functions of time.

Firstly, the acceleration components are approximated, with degree of a polynomial chosen with respect to the total number of boundary and continuous conditions, than velocity as integrated function of acceleration, and displacement as integrated function of velocity. All functions (i.e. coefficients) have been determined by solving system of equations.

Geometrical relations with regard to climbing dynamics will be used as model to present and calculate reaction forces on the wall and floor contact points in estimation of forces. At each time sequence, using the calculated climber's CoG kinematics and dynamics (shown in Figure 2b and Figure 2c, inertial force components are calculated, combined climber and ladder weight (which form a new line at each time sequence), a force polygon is constructed. Combined weights and inertia force form an active load force on the ladder. The wall reaction force has a predetermined line of action because it is expected that in all the considered cases of ascent the ladder sliding away from the wall is the tendency of motion, hence the sliding downwards determines the direction of the friction force on the wall contact point. It is assumed that the friction force on the wall is at its maximum, i.e. the angle of that reaction is $\alpha_A = \text{atan}(\mu_A)$. Angles between the forces in the polygon are determined from the geometry, i.e. intersections of force lines.

With determined acceleration and displacement functions, reactions on the wall and floor are then calculated in order to assess both of the safety conditions; separation from the wall and sliding on the floor.

From those results a diagram with limit curves for both safety conditions is constructed. In that diagram curves show where is the limit between safe and unsafe zone, in sense of slant angle vs. friction coefficient and climber's mass for a chosen climb period duration.

In the kinematics approximation scheme the first step is to approximate the form of acceleration in the x and z axis, respectfully, according to fig. 3a) and 3c). It is chosen that the components of acceleration through the climbing cycle will be described in 2 parts, for each coordinate axis differently. For the x axis the first part, a_x^1 , is in the time limits $t \in [0, t_1]$, in which it is presumed that person climbing is increasing the velocity, and the second, a_x^2 , in the time limits $t \in [t_1, T]$, with T being the cycle (period) duration, in which the person is decreasing velocity. For the z axis the first part, a_z^1 , is in the time limits $t \in [0, t_2]$, and the second, a_z^2 , in the time limits $t \in [t_2, T]$. The approximated acceleration functions of time by parts are of shape

$$\begin{aligned} a_x^1(t) &= a^1 + a^2t + a^3t^2 + a^4t^3 + a^5t^4, \quad t \in [0, t_1]; \\ a_x^2(t) &= b^1 + b^2t + b^3t^2 + b^4t^3 + b^5t^4, \quad t \in [t_1, T]. \\ a_z^1(t) &= c^1 + c^2t + c^3t^2 + c^4t^3, \quad t \in [0, t_2]; \\ a_z^2(t) &= d^1 + d^2t + d^3t^2 + d^4t^3, \quad t \in [t_2, T]. \end{aligned} \tag{1}$$

Several initial and continuous conditions on the acceleration functions have been imposed. Given the total number of kinematic conditions that can be imposed on the functions of acceleration, velocity and displacement, shown in detail further on, a variable point in the first part of the period ($0 < t_a < t_1$) is chosen, in which a value for acceleration is imposed to control the shape of the function. That time is defined as $t(a_{x, \max}) = k_1 t_1$. The value of

acceleration is denoted as “max”, however, it is not necessarily the maximum value, rather a control value. These conditions are as follows:

$$\begin{aligned} a_x^1(0) = 0, a_{x,t}^1(0) = 0, a_x^1(k_1 t_1) = a_{x,\max}^1, \\ a_x^1(t_1) = a_x^2(t_1) = 0, a_{x,t}^1(t_1) = a_{x,t}^2(t_1), a_x^2(T) = 0, a_{x,t}^2(T) = 0. \\ a_z^1(0) = 0, a_z^1(t_2) = a_z^2(t_2) = 0, a_z^2(T) = 0. \end{aligned} \quad (2)$$

Integrating over time the function of acceleration gives function of velocity as follows

$$\begin{aligned} v_x^1(t) = a^1 t + a^2 t^2 / 2 + a^3 t^3 / 3 + a^4 t^4 / 4 + a^5 t^5 / 5 + a^6; \\ v_x^2(t) = b^1 t + b^2 t^2 / 2 + b^3 t^3 / 3 + b^4 t^4 / 4 + b^5 t^5 / 5 + b^6. \end{aligned} \quad (3)$$

For velocity the boundary and continuous conditions are

$$\begin{aligned} v_x^1(0) = 0, v_x^1(t_1) = v_x^2(t_1) = 0, v_x^2(T) = 0, \\ v_z^1(0) = 0, v_z^1(t_2) = v_z^2(t_2) = 0, v_z^2(T) = 0. \end{aligned} \quad (4)$$

Integrating over time the function of velocity gives function of displacement as follows

$$\begin{aligned} u_x^1(t) = a^1 t^2 / 2 + a^2 t^3 / 6 + a^3 t^4 / 12 + a^4 t^5 / 20 + a^5 t^6 / 30 + a^6 t + a^7; \\ u_x^2(t) = b^1 t^2 / 2 + b^2 t^3 / 6 + b^3 t^4 / 12 + b^4 t^5 / 20 + b^5 t^6 / 30 + b^6 t + b^7. \end{aligned} \quad (5)$$

For displacement, the boundary and continuity conditions are

$$\begin{aligned} u_x^1(0) = 0, u_x^1(t_1) = u_x^2(t_1), u_x^2(T) = k, \\ u_z^1(0) = 0, u_z^1(t_2) = u_z^2(t_2), u_z^2(T) = 0. \end{aligned} \quad (6)$$

In (6) the index k denotes the rung spacing. Equations (1) through (6) form a system of equations, and after solving it, the kinematics components calculated are shown in Figure 3. For brevity, only kinematics components for cycle with $T = 1,5$ s are shown. Kinematics of cycle with $T = 1,0$ s is similar in shape, with different maximum and minimum values of acceleration. After calculating kinematics, dynamics is used to calculate load on the ladder.

Combined displacements on the x axis vs. time and on the z axis vs. time give CoG trajectory, now as a continuous function of time. Symbolically, trajectory of the climber’s CoG is shown in Figure 2a.

The inertial force is described, i.e. calculated, by two components, depicted with $F_{in,x}$ and $F_{in,z}$, in Figure 2b. Each inertial force component is calculated as $\vec{F}_{in,i} = -m_c \vec{a}_i$, with i being coordinate axis index. Resultant of the inertial force components with the combined climber and ladder weights, denoted G_{com} , form a ladder resultant load force denoted F_{res} . In Figure 2c line of the resultant force is then used to determine intersection with the line of the wall resting point reaction force, denoted F_A , and by that intersection line of the floor resting point reaction force, denoted F_B , is determined, shown in Figure 2c. In the same figure the range of the reaction (friction) force (friction angle) is shown with hatched triangles at each resting point. It is presumed that at each ascent cycle maximum of the friction force on the wall resting point (denoted A) is achieved, hence, it determines the angle of the reaction force line. It is also presumed that all the forces act in the ladder – climber system sagittal (symmetry) plane. The force polygon is then used to calculate reaction forces at each resting point by means of the vector equilibrium equation

$$\vec{F}_{res} + \vec{F}_A + \vec{F}_B = \vec{0}. \quad (7)$$

Based on the calculated reaction forces, a safety conditions are determined: separation from the wall, shown schematically in Figure 2d, and safety condition sliding on the floor, shown schematically in Figure 2e. The separation from the wall condition occurs when the reaction F_A is zero or less than zero, i.e. angular acceleration which leads to rotation of ladders clock wise in Figure 2d begins. The sliding on the floor condition occurs when friction force on the floor contact point is insufficient to balance action of the climber, and the angular acceleration counter-clock wise in Figure 2e begins.

In Figure 3a climber's CoG acceleration on the x axis calculated after solving system of equations (1) through (6) is shown, as a function of time. Figure 3b shows climber's CoG or displacement along the x axis, as a function of time. In Figure 3c climber's CoG acceleration on the z axis is shown, as a function of time. Figure 3d shows climber's CoG or displacement along the z axis, as a function of time.

The three forces forming a closed polygon are shown in Figure 4. Reaction forces are calculated from Figure 4 using the sine theorem as

$$\frac{F_R}{\sin(\alpha_3)} = \frac{F_A}{\sin(\alpha_2)}, \Rightarrow F_A = F_R \frac{\sin(\alpha_2)}{\sin(\alpha_3)}; \quad (8)$$

$$\frac{F_R}{\sin(\alpha_3)} = \frac{F_B}{\sin(\alpha_1)} \Rightarrow F_B = F_R \frac{\sin(\alpha_1)}{\sin(\alpha_3)}.$$

Time step taken in all the analysis of climbing dynamics, i.e. safety assessment was $\Delta t = 0,03$ s for the mild climbing kinematics, and $\Delta t = 0,02$ s for the intense climbing kinematics. For the assesment of safety in climbing activity, two criterias will be used; the first, will the climber act in such a way on the ladder to cause zero reaction on the wall, i.e. beginning to separate from the wall, and the second, if the friction force on the floor contact point, F_B , is insufficient to hold the ladder - climber system from sliding the point B away from the wall. Combination of parameters normalized climber's mass m_c , ascent cycle duration T , coefficient of friction on the floor, μ_B , used in the analysis, gave values for the safety conditions. In each time sequence (step) reaction forces have been calculated according to equation (8) based on kinematics and dynamics, and the safety conditions in sense of the minimum inclination angle for sliding, and maximum for separation from the wall abstracted. The results of this analysis are shown in diagrams in Figures 6 and 7. The two climbing kinematics, with $T = 1,5$ s as mild, and $T = 1,0$ s as intense, analysed, gave results "condensed" into curves in diagrams in Figures 6 and 7.

Both of the diagrams have an "upper" boundary curve, which gives relationship between the ladder inclination angle at which for a given normalized climber's mass and climbing cycle duration the wall reaction is zero or less, and separation from the wall begins. All the other curves in a diagram represent a boundary between the conditions with "enough" friction force to hold the ladder in static state, which is coefficient of friction on the floor and "allowed" slant angle below which safety from sliding is lost. This is explained in Figure 5 on just one curve for sliding condition. In a diagram for a chosen cycle duration, and friction coefficient on the floor, i.e. the measured or estimated in reality, the normalized climber's mass is parameter for which there are two curves which give intersections with line m_{norm} . One curve in diagram in Figure 5 is "lower", denoted $\mu_B = 0,25$, dashed, and the other is "upper", full (continuous). The upper boundary value for the inclination angle for $m_{norm} = 0,9$ for instance, is around 78° (separation from the wall above that angle), and lower boundary value is around 67° (below which sliding on the floor occurs). Between those two values is the "safe" range for the slant angle.

In Figures 6 and 7 all of the dashed curves represent boundary curves for sliding on the floor safety condition. For a given set of remaining parameters, as the friction coefficient rises, the

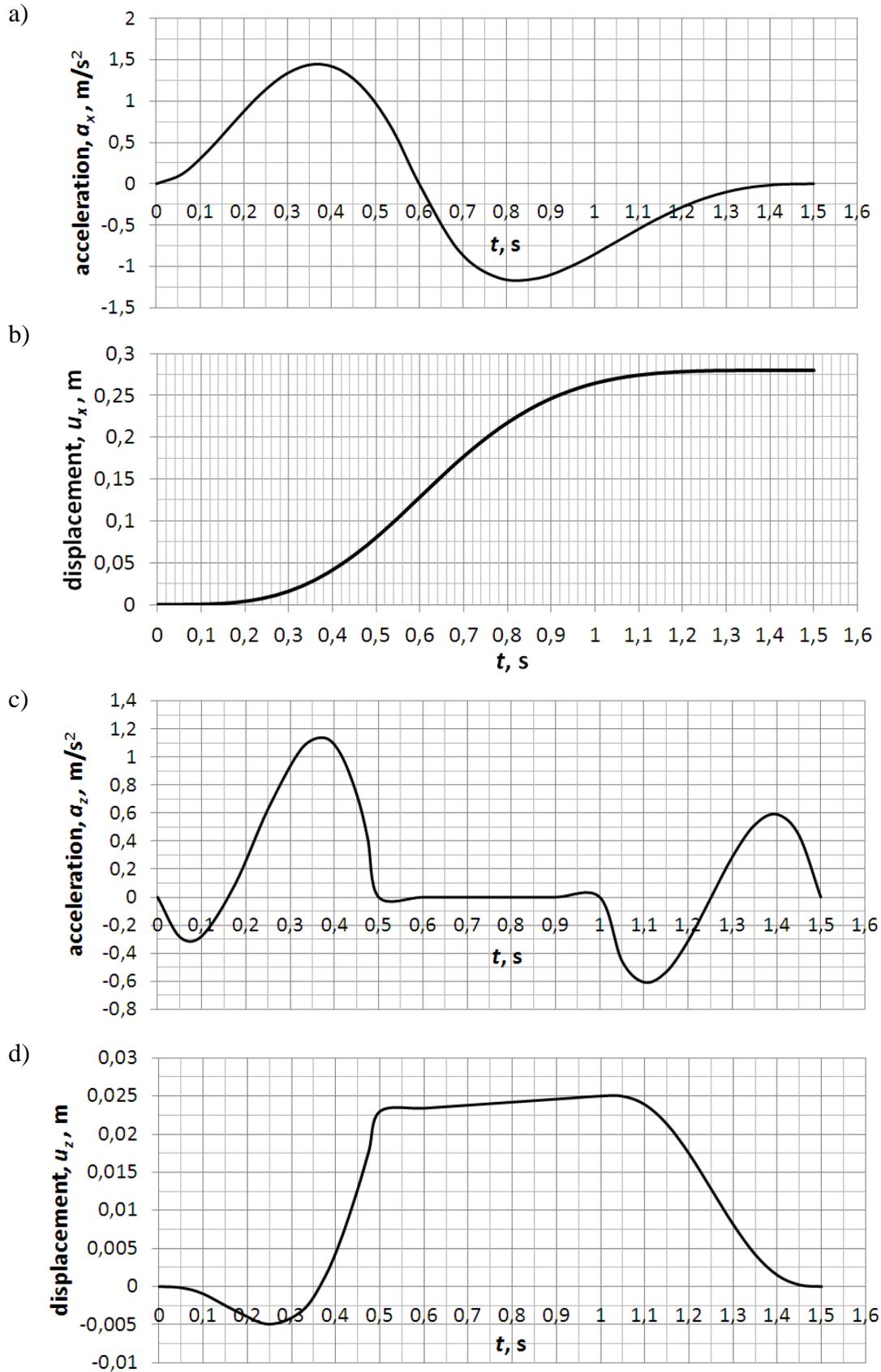


Figure 3. Kinematics of climber' CoG for mild climb ($T = 1,5$ s) cycle: a) and b) refer to direction along x -axis; c) and d) along z -axis.

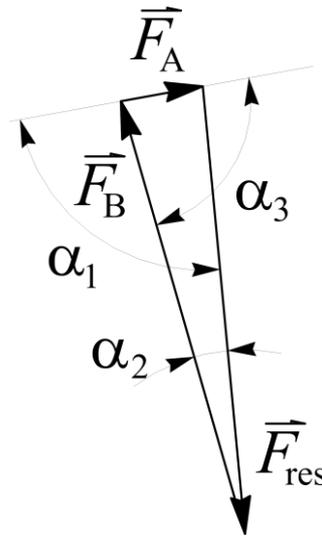


Figure 4. Forces polygon.

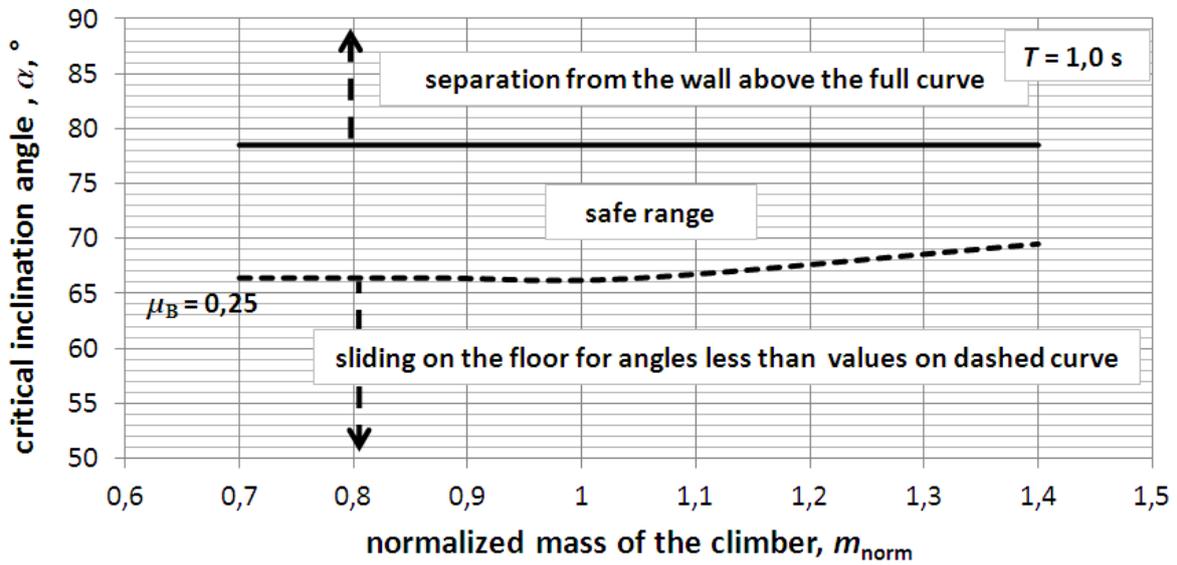


Figure 5. Explanation of the curve in safety conditions diagrams.

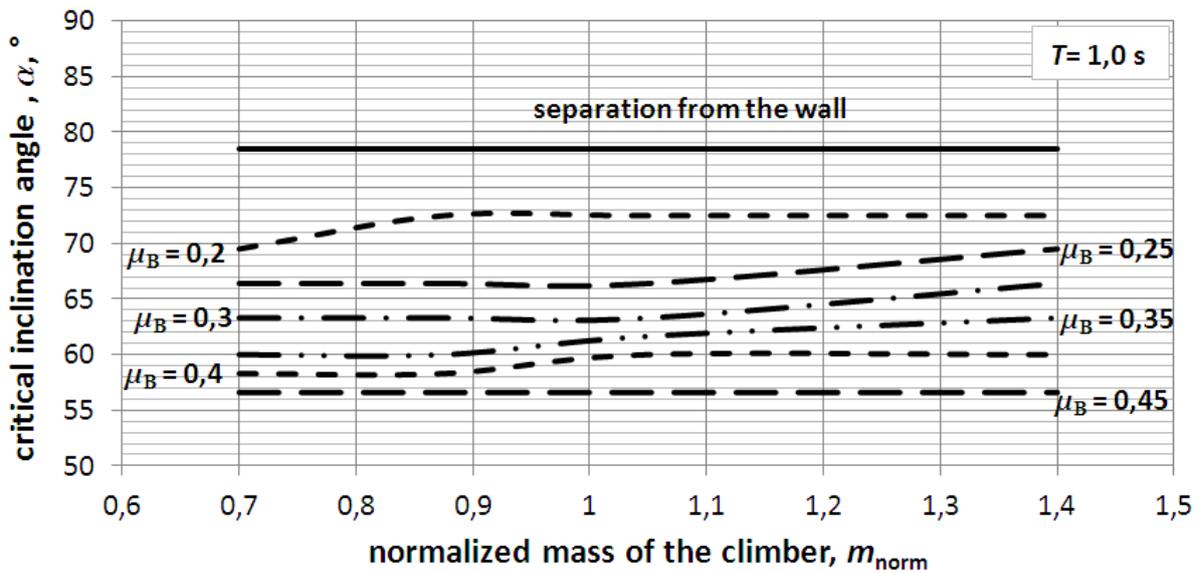


Figure 6. Conditions of safety for mild climbing kinematics.

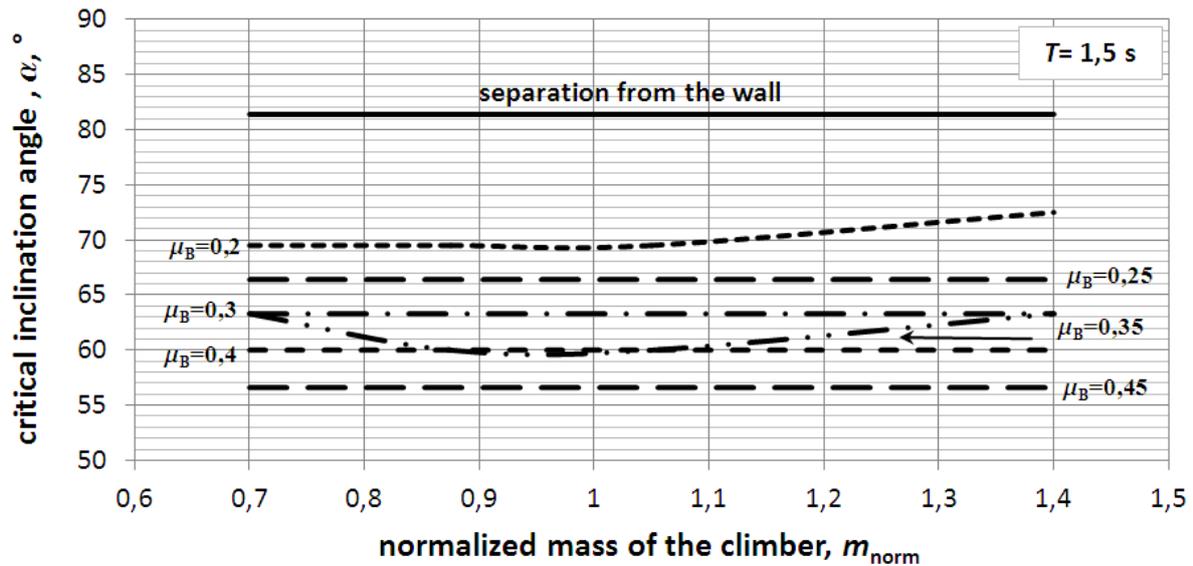


Figure 7. Conditions of safety for intense climbing kinematics.

minimum inclination angle lowers, as expected. Curves give the same “recommendations”, or conclusion that the inclination angle of $75,5^\circ$ is optimal for safe climbing in the described style (knees “within” the side rails) with described kinematics, with a low friction on the floor.

CONCLUSION

Primary goal of this article is to assess single rigid ladder stability in case of most unfavourable ascent style, with consideration of real time kinetics and kinematics, anthropometry of climber and variable contact friction factors. Ladder use model is defined as formed by a person, ladder, and environment. Analysis conducted confirmed our holistic consideration of the ladder use, and correspond to findings of others [6, 7, 9]. The kinematics of CoG has been described explicitly by interpolating polynomials by parts of ascent cycle, as a function of time. Displacement of CoG is described respectfully for each coordinate axis, i.e., along and perpendicular to the ladder longitudinal axis.

Results presented show how body kinematics reflects on safety assessment of ladder climbing dynamics. Described CoG trajectory, estimated as primarily sagittal motion, is employed to calculate dynamics of single ladder climbing, and based on the reactions on the wall and floor assess safety conditions. The two safety conditions considered are: separation from the wall, and sliding on the floor. Variable friction coefficients on the floor contact point have been considered, ranging from 0,2 to 0,45.

Slant angle of $75,5^\circ$ can be found in recommended regulations and scholar publications [6, 14, 15] as the safest ladder slant angle which is confirmed by this article. Within the results presented, safe ladder slant angle is determined to range from 73° to 78° that considered a wide range of friction coefficients on the floor (from 0,2 and up), climber’ mass and climbing ascent cycle duration, which also shows validity of the proposed kinematics description. This way, our objective to assess rigid ladder stability with variable use parameters has resulted with relevant comprehensions.

Secondary goal of this article was to validate created computational ladder utilization model and generated equations. Performed analysis of rigid single ladder usage affirmed validity of created computational ladder model and representative equations, which confirmed secondary goal accomplishment and ability to revise ladder use recommendations. Moreover, since analysis results confirmed compatibility with results of others [7-9], created model is

expected to enable further extension of ladder use parameters to be considered and analysed. Hence, inclusivity of wider range of parameters of ladder use is expected to reveal other underestimated or neglected factors that might appear as critical ones.

Author's prospective future scope is introduction of deformability of the side rails, i.e. taking vibrations into consideration, which will extend and enable more complex structural integrity analysis and ladder design evaluation.

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WORKING MEMORY FROM THE PERSPECTIVE OF THE MULTICOMPONENT MODEL AND EMBEDDED-PROCESSES MODEL

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DOI: 10.7906/indecs.18.4.2
Regular article

Received: 9 December 2019.
Accepted: 23 February 2020.

ABSTRACT

In this article, we focus on working memory, the ability to store and actively manipulate information for a short period of time, and present two prominent theoretical frameworks for its study: Baddeley and Hitch's multicomponent model of working memory and Cowan's embedded-processes model. The multicomponent model assumes modality specific "slave" components for temporary storage and rehearsal of information and a central executive component that controls the entire system and determines what information enters and leaves the stores. The embedded-processes model, on the other hand, gives a more general description of the working memory system by focusing on its processes. It assumes that attention allocated to representations stored in the long-term memory underlies the short-term maintenance of information. We further describe in more detail how models conceptualize and define working memory, its components, and the processes involved, as well as factors in limiting its capacity. Finally, we describe similarities and differences between the models and present how the components of the models can be mapped to one another and to the brain systems.

KEY WORDS

working memory, multicomponent model, model of embedded-processes, representations, active maintenance

CLASSIFICATION

APA: 2300, 2340, 2343

JEL: I12

INTRODUCTION

The aim of this article is to present the concept of working memory - the ability to store and actively manipulate information for a short period of time - from the perspective of two prominent theoretical frameworks for its study: Baddeley and Hitch's multicomponent model of working memory and Cowan's embedded-processes model. We first give a brief overview of what working memory is and how it differs from the concept of short-term memory within the scope of cognitive psychology and the functional level of the study of the cognitive system. Next, we present how the two models conceptualize and define working memory, its components, and the processes involved, as well as factors in limiting its capacity. Furthermore, we describe similarities and differences between the models and present how the components of the models might be mapped to one another. Finally, we present how the components of the two models can be related to the brain systems.

Working memory is one of the basic cognitive abilities, crucial for the successful execution of daily tasks such as remembering a telephone number, keeping up with the storyline while reading, solving math problems as well as adjusting to the ever-changing environment when driving a car. In contrast to short-term memory, which assumes simple storage of information for a short period of time [1], working memory refers to both temporary storage as well as active manipulation of information in order to achieve current task goals [2].

The term short-term memory was introduced by Atkinson and Shiffrin [1] in their multi-store model of memory, which assumes that human memory consists of three structural components: the sensory register, the short-term store and the long-term memory store. Information from the environment first enters the sensory register which is modality specific (e.g. vision, hearing) and can hold information for a brief period of time that varies across modalities from a few hundred milliseconds for visual sensory memory (also termed iconic memory) to a few seconds for auditory sensory memory (also termed echoic memory). If attention is allocated to the sensory stimulation, the information can be transferred into the unitary limited capacity short-term store in which it is present in an easily accessible state, and if rehearsed it can be further transferred into the essentially unlimited-capacity long-term memory for an indefinite period of time. By popularizing the term "working memory" a few years later, Baddeley and Hitch [3], who found Atkinson and Shiffrin's [1] model too simplistic, aimed to replace the concept of "short-term" memory by emphasizing its ability to actively manipulate information rather than only passively store it.

Active manipulation of temporarily stored information is central to cognition, as it forms the basis for higher cognitive functions such as reasoning, problem-solving and planning. Working memory correlates strongly with fluid intelligence [4] and is often impaired in diseases of the brain [5], its decline, however, is also a signature of healthy aging [6]. As such, understanding the mechanisms of working memory is of key interest in understanding human cognition.

One of the key challenges in working memory research is to understand the mechanisms of its highly limited capacity. In early research, primarily focused on verbal material, the capacity associated with the short-term memory was estimated to be roughly around 7 items or "chunks" of information of different types (words, letters, digits) [7]. It was later shown that the capacity estimate heavily depends on the type of information to be memorized (e.g. verbal, visual) as well as the complexity of the stimuli, such as phonological complexity for verbal contents, i.e. the number of phonemes or syllables [8] or complexity of visual representation (e.g. number of stimuli in a visual array) [9]. Therefore, when estimating the capacity, these and other factors affecting memory span must be taken into account, making capacity difficult to be summarized with one specific number valid within different contexts,

tasks and information types [4, 10]. Cowan [11], however, proposed that working memory capacity in young adults is about four chunks of information.

Though the debate in this field has first centered on the quantification of working memory capacity, the focus has recently shifted to the question of what are the cognitive system's properties that define working memory limited capacity – are the limitations due to limited capacity of modality-specific stores or limitations in attentional processes [12, 13]? A number of models that have evolved within the framework of cognitive psychology, neuroscience and computational modelling attempt to explain its limitations by describing its structures and components as well as their processes. Two of the key theoretical frameworks for studying working memory are Baddeley and Hitch's [3, 14] multicomponent model of working memory and Cowan's [4] model of embedded-processes.

THE MULTICOMPONENT MODEL OF WORKING MEMORY

According to Baddeley and Logie [15], working memory “allows humans to comprehend and mentally represent their immediate environment, to retain information about their immediate past experience, to support the acquisition of new knowledge, to solve problems, and to formulate, relate and act on current goals” [15; p.28]. In their multicomponent model of working memory, Baddeley and Hitch [3] describe working memory as a hypothetical system of limited capacity that enables temporary storage and manipulation of information needed to perform a number of cognitive activities. In their view, working memory is a system separate from long-term memory, though tightly connected with it. The model consists of several components: modality-specific temporary “slave” memory systems, which store information and refresh memory traces, and a supervisory system (the central executive) that controls, coordinates and regulates slave memory systems and activates contents from the long-term memory (Fig.1).

Initially, unlike Atkinson and Shiffrin's [1] unitary short-term store, two components for storing information were incorporated into the model [3]: a phonological loop tasked with maintenance of information in phonological form and a visuo-spatial sketchpad responsible for storing visual and spatial information. Baddeley and Hitch [3] further envisioned that the phonological loop consists of a passive ‘phonological store’ of limited capacity and an active ‘articulatory control process’ for refreshing memory traces and preventing them from temporal decay, which is the primary mechanism of forgetting in the multicomponent model working memory. By focusing on visuo-spatial working memory, Logie [9] upgraded Baddeley and Hitch's model. Analogous to the phonological loop, he envisaged that visuospatial sketch-pad also consists of a passive store for visual information (visual store) and an active system for refreshing and spatial manipulation of information (inner scribe) [9], although it is to date not entirely clear how visuo-spatial rehearsal is carried out.

In addition to the phonological loop and visuo-spatial sketch-pad, the central executive was also included in the original multicomponent model of working memory [3]. Baddeley and Hitch [3] envisioned the central executive as a supervisor, which manages the entire system and manipulates the information in the stores by determining what enters and leaves them. It is tasked with various executive functions such as focusing and switching attention, coordinating the slave systems as well as activating the contents within long-term memory. While slave systems are involved in the temporary storage of information and are of limited memory capacity, the central executive is not involved in information storage and its capacity is limited by attentional resources [2].

A fourth component, the episodic buffer, was added to the model almost 30 years later [14]. It is tasked with storing integrated information of various modalities in the form of short episodes and is tightly connected to long-term memory [14]. The initial assumption was that the storage of bound information depended on the central executive control of attention, but

empirical findings confirmed that the episodic buffer – in contrast to the phonological loop and the visuo-spatial sketch-pad, which contain their own mechanisms for information rehearsal – was a passive structure, which does not need the attention of the central executive to maintain information [16, 17], but rather that the central executive is needed to defend relevant contents against disturbing stimuli [17, 18].

In the multicomponent model of working memory representations are established in modality-specific components for short-term storage of information (phonological loop, visuo-spatial sketch-pad, and episodic buffer). Active maintenance of the representations established in buffer stores is enabled through their rehearsal processes (articulatory control process, inner scribe), as well as the central executive processes that control and regulate the information flow in subsidiary systems. In the multicomponent model, the storage of items in the working memory is distinct, though tightly connected to the contents of long-term memory. In the embedded-processes model, information in the long-term memory can be activated either automatically or voluntarily with the control of central executive processes. When the incoming sensory information is of high salience or when the information is activated by central executive processes it becomes part of the focus of attention, which enables its active maintenance. Note that solid borders denote limited working memory capacity components.

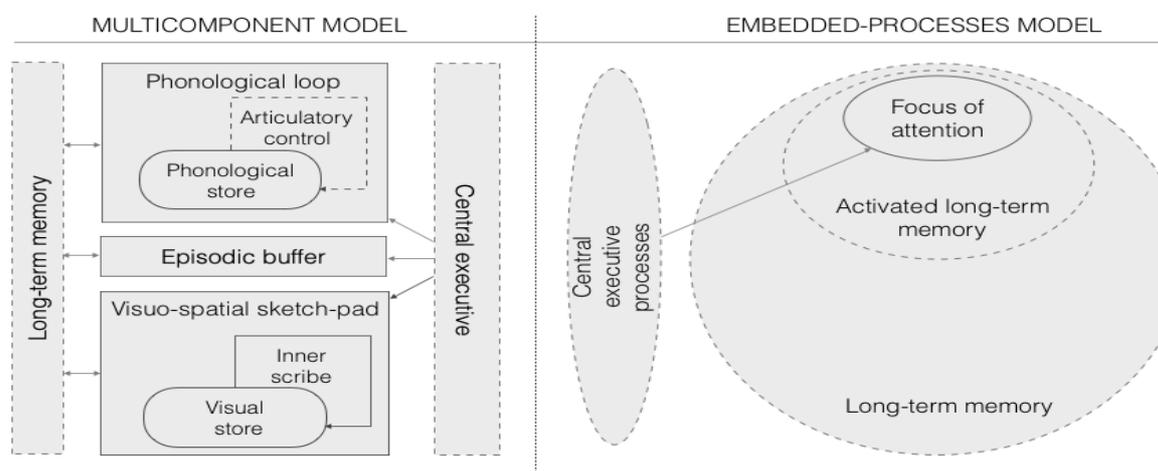


Figure 1. Comparison of the multicomponent and embedded-processes models of working memory.

EMBEDDED-PROCESSES MODEL

According to Cowan [19] “working memory refers to cognitive processes that retain information in an unusually accessible state, suitable for carrying out any task with a mental component” [19; p.62]. The idea of Cowan’s embedded-processes model [4], which is probably the most prominent representative of state-based models [20], is to give a more general description of the working memory system by describing the processes it involves rather than to divide its components based on the form of stored information, as in the multicomponent model [2]. Though Cowan [4] acknowledges that visuo-spatial and verbal memory represent two different systems, he argues that beyond verbal and visuo-spatial representations, other, equally important types of information might be stored in working memory. Cowan’s [4] idea with the embedded-processes model is therefore “to describe a processing model that is exhaustive, in that nothing is left out, even at the cost of the model being vague in places” [4; p.74].

In line with this view, instead of specialized temporary storage systems and a central executive that controls them, the model of embedded-processes sees working memory as a

system for controlling attention to the currently activated contents of episodic and semantic long-term memory. Within this perspective, attention allocated to internal representations that are stored either in long-term memory [4, 21] or established through sensory or motor systems [22, 23], forms the basis for short-term maintenance of information.

The embedded-processes model is a representative of unitary models of memory, as it assumes that working memory is an active part of long-term memory and identifies broader-to-more specific hierarchically organized components [4]: long-term memory, activated long-term memory and the focus of attention (Fig. 1). Activated long-term memory is a collection of long-term memory representations, that are currently activated and are as such in a particularly accessible state for a limited time. It does not have limited capacity in terms of how many representations can be activated a given moment, but is limited by time and is subject to interference effects. The second component is the capacity-limited focus of attention, which represents a subset of representations in the activated long-term memory. The focus is controlled either voluntarily by central executive processes or involuntary by orienting responses to changes in the environment. Whereas sensory representations can be activated automatically, attention is needed for integration of representations and forming new bindings in working memory.

SIMILARITIES AND DIFFERENCES BETWEEN THE MODELS

Although the models seem to differ to a great extent – the components in the multicomponent model are divided based on the properties of stored information (verbal, visuo-spatial, integrated information), while the focus of the embedded-processes model is on the components' functions – both Baddeley [2] and Cowan [4] see them as essentially complementary [9]. Baddeley [2] argues that “At a superficial level, Cowan’s theories might seem to be totally different from my own. In practice, however, we agree on most issues but differ in our terminology and areas of current focus. /.../ I regard our differences as principally ones of emphasis and terminology” [2; p.21]. Cowan’s [4] view is similar: “Thus the difference between the working memory model of Baddeley (2000) and the embedded-processes model is not very large and is probably best viewed as one of the level of analysis: a level of specific phonological, visuo-spatial and episodic storage properties versus a level of general principles of activated memory and attentional focus” [4; p.84].

The models can be compared in a number of ways and herein we only discuss a few. First, the models can be contrasted in how they see working memory in relation to sensory input and long-term memory. Both the multicomponent model [2] as well as embedded-processes model [19] see sensory input as separate from the contents stored in the working memory [9]. This view is similar to what was proposed by Atkinson and Shiffrin [1]. The multicomponent model assumes that sensory input is first processed by the perceptual systems and can then be transferred, manipulated and stored in the slave components with the help of attention from the central executive, and also by interacting with the long-term memory. Similarly, the embedded-processes model assumes that the sensory input that induces brief sensory afterimages first excites relevant features in the long-term memory, which can then enter the focus of attention either automatically or with the help of executive processes [4]. However, they differ in how they see a connection to long-term memory. The multicomponent model [2] assumes that working memory is distinct, though tightly connected to the contents of long-term memory, whereas the embedded-processes model sees working memory as an activated part of the long-term memory [19].

Second, the models can be compared in terms of the specific mechanisms they propose for the working memory information loss. Working memory literature proposes two main mechanisms of information loss [24]. One possibility is that if not constantly refreshed, the information decays in accuracy and distinctiveness until it cannot be reconstructed anymore.

The other possibility (sometimes referred to as sudden death [24]) is that information is kept in a stable form without loss of accuracy, and the loss of information occurs instantly due to interference, e.g. interfering information replaces the existing information. Multicomponent model of working memory gives primacy to decay [2], whereas interference is more often referred to in state-based models [4].

Third, the models can be contrasted with regard to the systems and processes they involve. Both propose two systems that are involved in the maintenance of information – one is responsible for establishing and storing representations and the other for their active maintenance. The multicomponent model assumes [2] that representations are established and maintained in the slave components' stores (phonological store, visual store, episodic buffer), and that their active maintenance is enabled through their rehearsal processes (e.g. articulatory control process, inner scribe), as well as central executive processes that control and regulate the information flow in subsidiary systems [15]. In the embedded-processes model [4] representations are established within the long-term memory system, whereas central executive processes enable their active maintenance in the focus of attention.

Though the models are similar in that they both assume that two systems are involved in the maintenance of information, it is however not entirely clear whether and how their components can be mapped to one another. In Cowan's [4] view, his activated long-term memory maps onto Baddeley's temporary storage systems: "Activated memory was meant to serve the same purpose as Baddeley's two buffer stores together (phonological and visuo-spatial), plus any other buffer stores that might be posited in the future." [4; p.78]. Though no modality-specific buffer systems are specified in Cowan's [4] model, Cowan does acknowledge that activated portions of long-term memory can relate to distinct buffers. Moreover, he recognizes the role of central executive processes in focusing attention in both models, and links the role of this focus of attention to bind information to Baddeley's episodic buffer. Similarly, it can be understood that Baddeley [2] also maps his episodic buffer to Cowan's focus of attention and contents stored in the buffer stores to Cowan's activated long-term memory: "I see Cowan's model as principally concerned, in my terminology, with the link between the CE [central executive] and the episodic buffer". Cowan refers to the material on which his system works as "activated LTM [long term memory]" [2; p.20].

Another important aspect when comparing the two models is how they explain limitations in working memory capacity. In the multicomponent model, the limited capacity of the working memory is viewed as a result of an interaction between the operations of multiple components and subcomponents, and can be understood as an emergent property [9]. Multicomponent model assumes that central executive itself does not store any information, rather than its functional role is limited by attentional resources. Information storage systems are limited in terms of how much information they can store [9]. Moreover, unless refreshed by rehearsal, representations stored in phonological and visual store are subject to temporal decay, due to which information is lost in about two seconds. Though the processes for rehearsing information (i.e. articulatory control process for verbal information and inner scribe for visuo-spatial information) have no limit in terms of how many units of information they can refresh, they can only refresh information that is currently present in the buffer stores and as such depend on their capacity.

Whereas the main limitation of working memory capacity in the multicomponent model can be ascribed to the buffer store's capacities, in the embedded-processes model limitations are primarily related to the limited capacity of the focus of attention, as the central executive enables active maintenance in the focus of attention only for a limited number of representations in the activated long-term memory. On the other hand, the activated long-term memory itself has unlimited memory capacity and is limited by temporal and interference effects [4].

MODELS IN RELATION TO BRAIN SYSTEMS

The models presented here provide a conceptual description of the structure and processes of working memory at the functional level of the cognitive system. To gain a full understanding of working memory in human cognition, it is crucial to see how the functional models relate to neuroscientific findings. Although the models themselves do not provide explicit mapping to brain systems, they are consistent with the findings of neurophysiological research showing that posterior and prefrontal areas of the cerebral cortex play different roles in the short-term maintenance of visual-spatial information [25]. Studies show that the posterior areas of the cerebral cortex are involved in the formation and short-term storage of the visual, spatial and verbal representations [26], whereas prefrontal regions control allocation of attention for their active maintenance [27]. The role of prefrontal areas thus resonates with Cowan's executive processes that control what is in the focus of attention and Baddeley's rehearsal processes which refresh information from the stores to keep it active, as well as the central executive, which carries out the active work by controlling the contents in the buffer stores. Within Cowan's model the posterior regions are associated with both activated long-term memory as well as focus of attention [4], whereas in the multicomponent model the posterior regions are associated with contents in component-specific stores, including the episodic buffer [2].

Recent findings from neuroimaging studies (for a review, see [28]) show that the posterior brain regions that are involved in temporary storage of information are not unique to working memory, but are also involved in storing long-term memory representations as well as the sensory processing of information [29, 30]. These findings are consistent with the embedded-processes model, which assumes that the focus of attention to currently activated long-term memory representations underlies working memory.

CONCLUSION

As Baddeley [2] states, the idea of the multicomponent model of working memory which also holds true for the embedded-processes model is "a relatively loose theoretical framework rather than a precise model that allows specific predictions." [2; p.7]. The models must therefore be understood as hypothetical accounts of working memory structure and function. Although the models successfully explain many of the cognitive phenomena associated with the short-term storage of information and its active manipulation, and can be in many respects meaningfully mapped onto the brain function, their purpose is not to explain all of its aspects. They can instead be understood as working platforms that need to be further developed in accordance with empirical findings.

ACKNOWLEDGMENT

The author acknowledges this article was financially supported by the Slovenian Research Agency project grants J7-5553, J3-9264, and programme P5-0110. This manuscript is an extended version of the article *Two approaches to defining and studying working memory* presented at the Information Society multiconference held in Ljubljana (7 October - 11 October 2019) on the initiative of the Expert Committee.

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