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MAXIMISING PERFORMANCE OF A HOSPITAL'S HBOT LABORATORY USING THE THEORY OF CONSTRAINTS

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Purpose: The paper presents an application of the Theory of Constraints (TOC) aimed at defining and maximising the potential of hyperbaric chamber as a key resource in a specialist hospital.
Design/methodology/approach: The authors developed their own TOC based method of process improvement, supported by tools of Lean Management. Various constraints including an external one were taken into consideration. As a follow-up a project using the method was carried out in a hospital's Hyperbaric Oxygen Therapy laboratory.
Findings: The developed and implemented practical solution has improved patients' access to the service at about 40% per day, shortened patients' waiting time at about 90% and helped to overcome the threat of financial underperformance. Moreover, in combination with strict safety rules, the solution has proven its high resistance against difficulties caused by the COVID-19 pandemic.
Research limitations/implications: A hyperbaric therapy is a narrow branch of medicine, therefore application of the method in other healthcare domains will require an appropriate adaptation.
Practical implications: Despite the narrow subject of the study, the described approach is universal and can be used to maximise the capacity utilisation of various critical resources in hospitals and other healthcare providers.
Originality/value: This is the first known to the authors application of a TOC/Lean based systematic hybrid approach to improve performance of a healthcare provider, which is taking into account several constraints including an external one. Additionally, this is the first paper on TOC in healthcare published in Poland.

Keywords: critical resource, healthcare improvement, hyperbaric oxygen therapy, theory of constraints, lean healthcare, throughput.

Category of the paper: case study.

1. Introduction

Scientific advances in the past 120 years are associated with a great progress in diagnostics and treatment. At the same time, broad access to new treatment methods, even in well-developed countries, is still limited. The quality of medical services often leaves much to be desired, while an immense amount of public and private money spent on healthcare is wasted and the results achieved are far from being satisfactory (Nadziakiewicz, 2019a).

Improvement of the quality of medical services became a topic of interest for physicians after the first World War. Over the subsequent years many countries established institutions to develop and popularise standards of medical and medicine-related management. These bodies conduct audits of healthcare centres willing to undergo an evaluation, and they issue accreditation certificates to the units that meet clear-cut criteria. In some countries this may lead to the possibility of additional funding by the payer.

Effective hospital management is crucial for the implementation of the tasks defined by the Cost/Quality/Access (CQA) triangle (Bergeron, 2006). In the 1980s, researchers studying the problem of healthcare quality pointed out the similarity between the accreditation requirements and the principles of total quality management (TQM) described by Deming based on Japanese experiences in various types of industries. The trend started gaining momentum after 2000, when the management approaches developed primarily for production, such as Lean Management (Lean), Theory of Constraints (TOC), Six Sigma, and the tools used in their implementation (Kosieradzka et al., 2011) found successful applications in healthcare (Graban, 2008; Kenney, 2011; Sproull, 2019; Lisiecka-Biełanowicz, and Lisiecka, 2020). The other, more general quality management systems eg. based on ISO standards are also being widely used within healthcare industry (Nadziakiewicz, 2019b).

To the knowledge of the authors this is the first publication on such a hybrid approach dealing simultaneously with various types of constraints including an external one in case of a healthcare provider. The method has also proven to make a positive impact on CQA-triangle based global measures applied in healthcare.

TOC, like TQM and Lean Management is based on the principle of continuous improvement. In Lean the rules of continuous improvement use the concept of kaizen (Graban, and Swartz, 2012). In TOC it is referred to as POOGI (Process Of On-Going Improvement). Goldratt suggested three POOGIs: Change Question Sequence (CQS), which provides gap analysis, five focusing steps (5FS), which provide general framework for improvement and buffer management (BM) which is a mechanism ensuring utilizing the constraint to its full capacity (Bacelar-Silva et al., 2020).

There are three major categories of constraints: physical, policy and paradigm. All three exist in any given system at any given time and they are related (Scheinkopf, 1999). Other types of constraints can also occur, such as seasonal peak-time resource constraints or dummy constraints, often resulting from a faulty policy or following outdated procedures (Ronen et al., 2018).

Problem solving is inherent to management. The vast number of analytical and problem solving management tools was developed over the past 70 years. Basing on his experience, Goldratt developed an integrated set of methods comprising the Logical Thinking Process (Dettmer, 2007). They are presented in a form of logical diagrams which can be used as a complete system or stand-alone tools:

a. Intermediate Objective Map (IO Map) – serving as a roadmap to destination.
b. Current Reality Tree (CRT) – diagnostics; examining logic of current situation.
c. Evaporating Cloud (EC) – conflict resolution diagram.
d. Future Reality Tree (FRT) – presenting and verifying the future/desirable situation.
e. Prerequisite Tree (PRT) - presenting the sequence of actions.
f. Transition Tree (TT) – implementation of actions.

In the first decade of the 21st century only a limited number of publications regarding TOC in healthcare were available, compared to TQM or Lean. The first TOC applications in healthcare environment were referring to buffer management aiming at improvement of patients' throughput as defined in Section 2 without compromising the quality of care (Umble, and Umble, 2006; Knight, and Stratton, 2010; Stratton 2012). Application of logical thinking tools and overcoming resistance to change in the British hospital were described in a form of business novel (Wright, and King, 2006). As the popularity of the TOC concept increased, more cases were reported to use a variety of tools in different hospital operations (Aguilar-Escobar et al., 2015; de Souza, Souza, Vaccaro, 2016). The complete models of for-profit medical centre (Wadhwa, 2010) and large scale health systems (Wright, 2010) in *The theory of constraints handbook*, provided a major step ahead in TOC healthcare applications.

Over the past decade, researchers have examined the unique, TOC-specific logical processes (Mabin et al., 2017; Bauer et al., 2018; Cox, and Schragenheim, 2019) in healthcare settings. An increased number and extended range of materials published on TOCICO websites – medical appointment systems (Cox and Robinson, 2012), solving complex problems (Cox, and Schragenheim, 2019), and managing private medical practice (Bacelar-Silva, 2019) have demonstrated the advantages brought about by focusing on the constraints. Several books offering practical solutions for healthcare environment were published. In 2014, Alex Knight's experience with the complete implementations of TOC in British hospitals was encapsulated in the form of a novel which provides a valuable guide for the managers and doctors alike (Knight, 2014). Simultaneously, a methodology combining TOC, Lean and Six Sigma (TLS) was proposed (Inozu et al., 2012; Ronen et al., 2018; Sproull, 2019; Strear, and Sirias, 2020). The outcomes of managing healthcare services using TOC were assessed and summarized in the first systematic literature review (Bacelar-Silva et al., 2020), almost exactly 10 years after the first literature reviews regarding Lean (de Souza, 2009; Mazzocato et al., 2010).

Historically, Lean preceded TOC in wide-scale healthcare applications at about 10 years and became probably the most popular modern management system approach in healthcare (Lean healthcare). While the main goal of TOC is to focus on what is most important namely to improve the performance of the whole organization, Lean concentrates on waste elimination and process flow. Like in case of TOC, Lean has developed specific tools and concepts, including: 5S (workplace organisation), standard work, Just-in-Time, Value Stream Mapping (proces flow mapping), Kanban (pull system), Heijunka (production levelling), visual management, mistake proofing (Jackson, 2009; 2012; 2017; Jimmerson, 2010; Kerpchar et al., 2015).

Although the Lean healthcare application cases provided researchers and practitioners with encouraging results, the drawbacks were also identified. Several authors reported actual and possible barriers for Lean implementations, resulting from fragmented and undisciplined approach. (Radnor, and Osborne, 2012; Noori, 2015; Leggat et al., 2015; Leite et al., 2019). The abovementioned combination of TOC, Lean and Six Sigma facilitates keeping focus, flow, waste elimination and variability under strict control and increases the opportunity for improvement as mentioned above (Inozu et al., 2012). Combining the strengths of various management concepts depending on the needs was further described in details by Ronen et al. (2018) and Sproull (2019) and became a basis for the method described in this paper.

The paper has been divided into 5 sections. Section 1 presents the purpose of the article in the context of hitherto applied healthcare improvement practices based on the concepts developed primarily for manufacturing industry. In Section 2 structure and tools of the authors' own method have been described. Its detailed application oriented at performance improvement of hospital's critical resource (HBOT chamber) is the subject of Section 3. The discussion of findings has been presented in Section 4. Section 5 summarises the case and presents recommendations on dealing with the resistance against change in continuous improvement projects in healthcare.

2. Materials and Methods

The method developed for the project is based on all three POOGI-s as mentioned in Section 1. It comprises goal and measures and original Goldratt's 5S model which therefore becomes 7FS as described by Ronen and co-workers (Pass, and Ronen, 2003; Ronen et al., 2018):

1. **Determine the goal of the organisation** – The general goal of the hospital is to maximize the number of succesfully treated patients in a shortest possible time ensuring the best economic result possible.

2. **Define the measures for the organisation** – Every action undertaken inside the organisation should be evaluated in relation to its effect on the whole organisation. Ronen and co-workers suggested six global measures adapted to the specific healthcare environment (Ronen et al., 2018):
    a. Throughput (T) – a concept originating in accounting; it is the rate at which the system produces *goal units* through sales. In healthcare context, the meaning of throughput changes. Goldratt stated: *it is how many health units have you created – that's what counts* (Goldratt, 2001). Another definition is the *rate at which a patient moves through a location* (Strear, and Sirias, 2020). Measuring and standardising *health units* would be difficult to define and perform, therefore Goldratt introduced suggested to increase T indirectly, by eliminating undesirable effects (UDE) (Dettmer, 2007). This, he assumed, would result in growth of T and wider access to medical services. According to the most universal definition, T comprises two components: goal units, expressed as the number of patients who went through the system within time unit, and the related financial aspect (Ronen et al., 2018).
    b. Investment (I) – Goldratt introduced a classification into passive inventory – inventory being worked on – and active inventory (Dettmer, 2007). In production companies, passive inventory indicates raw materials, in hospitals it refers to the patients. Active inventory is all of the money tied up within the system.
    c. Operating Expenses (OE) – all of the money used by the organisation to transform inventory into throughput.
    d. Response Time (RT) is a measure or a set of measures to determine the time in which the system responds with an action to a patient's need. Depending on the situation, one or several RT measures can be introduced.
    e. Quality measures (Q) are one or more parameters measuring the degree of fulfilling or exceeding the client's (patient's) needs.
    f. Due-date Performance (DDP) is a measure or a set of measures assessing the hospital's capacity to deliver services within the planned time-frame.
3. **Identify the constraint** – A resource constraint (bottleneck) is a resource that prevents an organisation from achieving better results measured against its goals. Usually, such a constraint is identified through the observation, with special attention paid to the areas that generate the longest queues.
4. **Exploit the constraint** – To exploit the constraint to its maximum capacity, it is necessary to identify all of the possible reasons of incomplete exploitation of its potential, policy constraints. A schedule to maximise the use of resource constraint should be developed. This schedule is referred to as Drum, and is a part of the DBR (Drum-Buffer-Rope) concept application.

5. **Subordinate all other resources to the constraint** Typically, the schedule of maximising the use of the bottleneck is insufficient to provide proper operation, as its implementation is affected by various disturbances generated by other resources. Therefore, additional parts of DBR – Buffer and Rope – must be applied, in order to subordinate other actions in the analysed system to a flawless functioning of the constraint (according to the Drum schedule). These additional solutions are classified as:
    a. Buffer (physical) – a limited number of patients in the queue placed before the constraint in order to guarantee timely work at the bottleneck, even if adverse events impair its normal operation.
    b. Rope (time buffer) is a mechanism to determine the time for starting the first operation in the process, so that the right number of patients could get on time to the constraint, considering the performance time of all of the operations conducted prior to the bottleneck operation, and all potential breaks.
    c. The next step when the remaining policy constraints should be identified and eliminated is subordination of all resources to the resource constraint. Policy constraints are identified in a control test: *If we could break the policy constraint, could we increase throughput?* If the answer is *yes* then the policy constraint affects the system (Ronen et al., 2018).

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6. **Reinforce the constraint, and strive to finally overcome it** – Reinforcing of the constraint is taken into consideration only after the advantages offered in the previous steps have been exploited. E.g. if the constraint is the capacity of an internal resource, more of that capacity is acquired. If the constraint has been overcome, it is not a constraint anymore.
7. If steps 3-6 result in breaking the constraint, **the next weakest resource of the system becomes the new constraint**. At that point, one should return to step 3 and repeat the 5FS cycle from the beginning taking care to prevent inertia caused by outdated procedures. The cyclic overcoming of subsequent constraints is, however, not practical. Whenever possible and justified, the original constraint should be left in place, and prior to its extension, the next weakest link(s) should be identified and exploited to the capacity bigger than that of the widened original bottleneck (Goldratt, 2001).

Table 1 presents the phases and tools used in the method of improving processes using TOC, developed at the hospital. The first two steps of the model (the goal and the measures) are prerequisites for the remaining ones.

Table 1.
Phases and tools of the method used at the hospital

Phase	Description	Basic tools
I	Why change? Identification and description of the causesbehind the project	Analysis of the statistics of resource use Financial data analysis (based on the contract with the National Health Fund)
II	What to change? Problem identification/constraint identification	Current Reality Tree (CRT)
III	What to change to? Development of the direction of change	Future Reality Tree (FRT)
IV	How to implement the change? Development of the method to implement the change	Exploit the constraint – DRUM
		Subordinate BUFFER – ROPE
		Elevate the constraint
		TT – Transition Tree
		PRT – Prerequisite Tree
V	How to measure and sustain the change? Measuring and sustaining the change with appropriate tools	Measures: • Throughput • Investment • Operating Expenses • Response Time • Quality • Due-date performance

Source: own elaboration.

3. Results. The HBOT laboratory performance improvement – case study

The hyperbaric laboratory is equipped with a multiplace hyperbaric chamber with capacity designed for up to 14 patients. A session in the chamber lasts 1.5 hours. The pressure inside the chamber is 2.5 times higher than the atmospheric pressure. Oxygen is delivered through masks. Hyperbaric oxygen therapy (HBOT) is used in the treatment of wounds of various aetiology, including burns, sudden idiopathic hearing loss, decompression sickness, and in carbon monoxide (CO) poisoning. Treatment in such a chamber requires a physician's referral.

During each session, a trained attendant must be present. He or she participates in the session together with the patients, and reacts in case of adverse situations. An anaesthesiologist trained in hyperbaric medicine must also be present at the HBOT laboratory.

The project started in April 2018. Treatment of patients in most cases usually requires a series of 30 therapeutic sessions, conducted on weekdays for six consecutive weeks. Exceptions to this rule include emergencies, e.g. CO poisoning, when prompt therapy is required. The project focused on improvement of the chamber's use on weekdays only. Emergencies are irregular, and require immediate action, but they do not have a significant effect on the total number of procedures performed. The average total daily target of 80 patients was based on the contract with the National Health Fund. Prior to the project implementation, 5 sessions per day were scheduled for only 70 outpatients. Hospitalised patients participated in the separate session after the planned ones were completed.

Participation in the planned therapeutic sessions requires regular and punctual arrival of patients at the HBOT laboratory on the appointed dates. It was never a problem with the hospitalised patients, however, some of the outpatients did not notify in advance about their absence on a given day, or came to a different session than the one that had been planned for them. As a result, during many sessions, the chamber was used only partially. The absence of a mechanism to fill in the empty places, and overlapping of the described situations often made it impossible to schedule sessions for the required 80 patients for the following day.

Deficient use of the chamber prevented ongoing reduction of the queues of patients waiting for sessions, which resulted in limited accessibility to this medical service, meaning a prolonged (5-6 months) waiting time for the initiation of the therapeutic cycle in the case of outpatients. It also meant additional use of the hyperbaric chamber for the patients who did not come to the planned session during the day but came after the last session had been completed.

Furthermore, using the chamber at incomplete capacity was leading to imbalanced personnel workload. The limit of compressions for attendants in a given time interval (one compression in 24 hours), based on the work and safety regulations, was a potential peak-time constraint that prevented conducting a higher number of compressions per day. Additional sessions were associated with additional costs related to chamber operation (oxygen, materials), overtime of the personnel operating the chamber, and costs of additional activities, e.g. disinfection. It posed a threat to the hospital's financial performance, as the number of compressions continued to remain 10-25% below the year-to-date target in the months preceding the project's implementation If a contract executed by a hospital is less than 98% of the target, it contributes to reduction of contract for the next financial year. Due to the chamber operating at incomplete patient capacity, the throughput at the hospital was lower than that established in the contract, while the costs were higher than they would have been if sessions were held regularly and at full patient capacity. The hospital was able to perform more sessions (7 to 8 per day), and saw prospects for further expansion in this direction, e.g. by co-operation with other hospitals and emergency services. The chamber seemed an apparent bottleneck, whereas the actual cause of the constraint was the lack of a policy for full use of the chamber during each session.

3.1. What to change?

This problem was illustrated with an aid of a Current Reality Tree (Figure 1). The core problem, i.e. absence of a coherent policy for the use of the chamber at 100% patient capacity, resulted in only partial utilisation of the chamber in successive sessions. As a consequence, additional sessions were required, which generated extra costs, prevented implementation of the target, increased waiting time for therapy initiation, and – together with the limited number and accessibility of attendants – could lead to session cancellations. This, via a feedback loop, increased the source problem, further aggravating the situation.

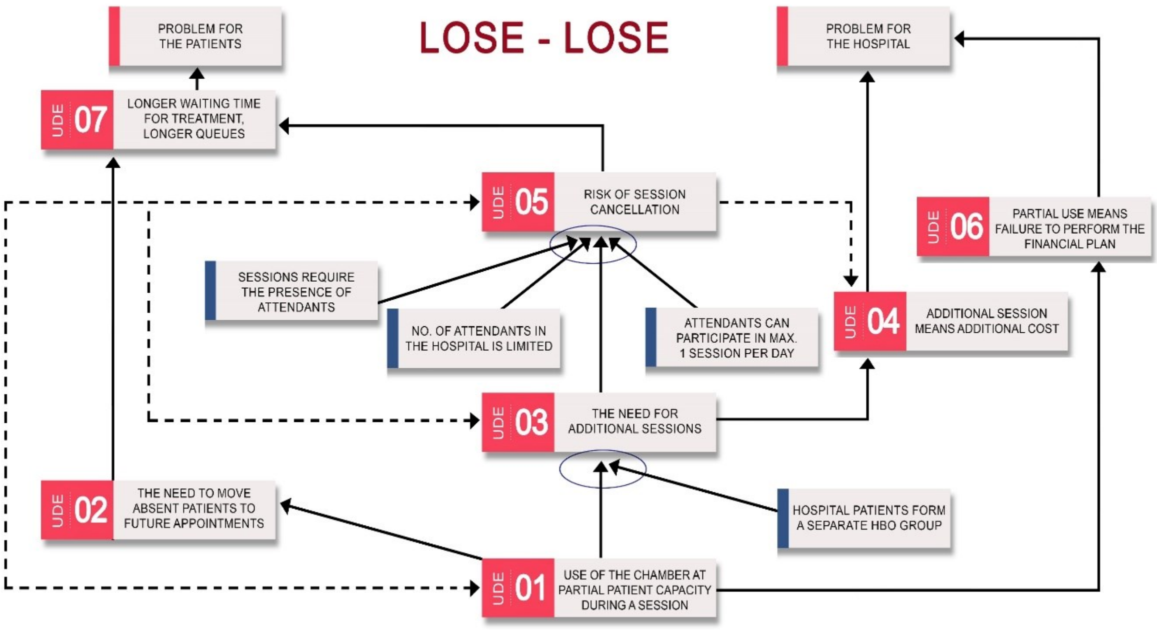

Figure 1. Hyperbaric chamber – Current Reality Tree. Source: Own elaboration.

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3.2. What to change to?

The analysis revealed that at the time of project initiation, the number of attendants at the hospital was sufficient to cover the current market demand under the abovementioned existing safety regulations. This was enough to achieve annual targets, provided the chamber was used to its full patient capacity.

As the potential of the HBOT laboratory was greater than the number of patients referred to it, the constraint associated with the chamber is, in fact, external. The primary constraint preventing an accurate diagnosis of the situation was the lack of the appropriate policy. As this was part of standard practice for years, the problem was difficult to detect.

It should be noted that in the case of not using the chamber to its full capacity, the risk of an internal constraint has been detected as a result of limited number of attendants, due to their workshift limits regulations on their participation in sessions. The decision to exploit the constraint to its maximum had to involve breaking the constraints resulting from earlier habits and procedures. Figure 2 presents the evolution of the constraint.

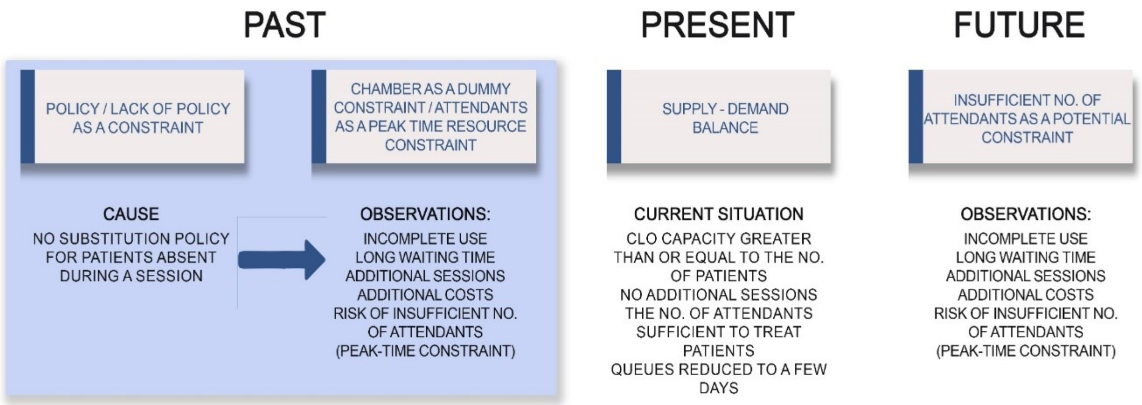

Figure 2. Constraint/constraint perception evolution in the course of the project. Source: own elaboration.

To fully exploit the external constraint, the chamber throughput had to be subordinated to it. This is achieved by maximising the number of patients during each session. The solution was based on dynamic control of the chamber's performance, so that it would always be used to its full capacity. This allowed to overtake for the delay in contract execution since the beginning of the year, and enable more extensive use of the chamber in the future.

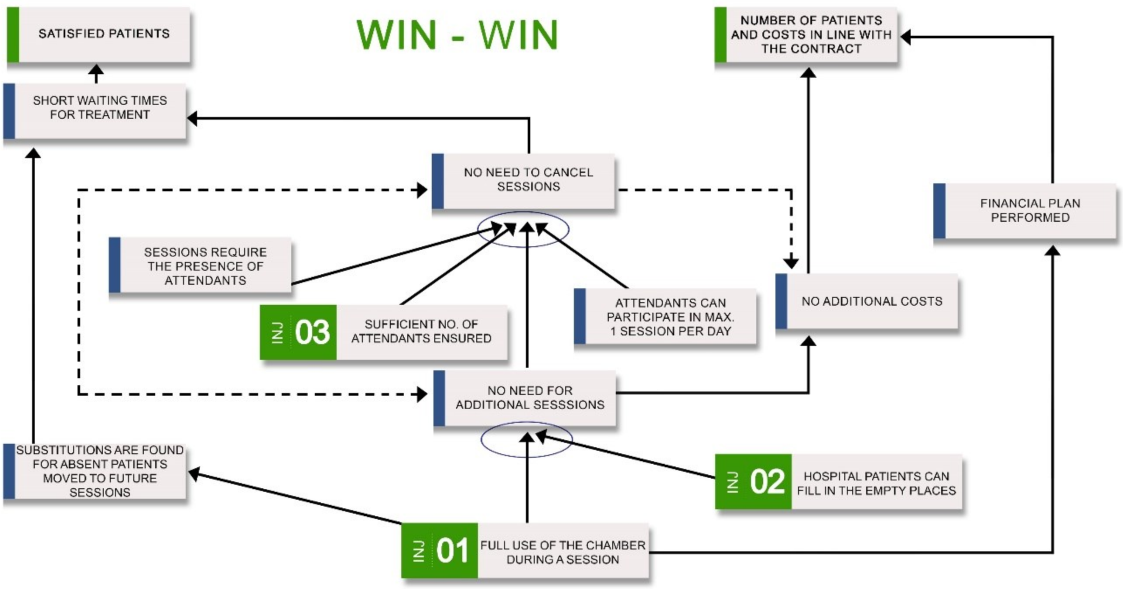

Figure 3. Hyperbaric chamber –Future Reality Tree. Source: own elaboration.

Figure 3 presents the Future Reality Tree. If the chamber is used to its full patient capacity, and hospital patients can substitute for the absent outpatients, all available seats are used, and the absent patients are allocated dynamically to future sessions. Therefore, the waiting time for the first session after the qualification for hyperbaric oxygen therapy is reduced.

In the case of a sudden increase in market demand, it would be possible to break the existing constraint, and identify a new one, i.e. a shortage of attendants. It is much more beneficial for the hospital, to retain the external constraint; therefore, as a solution INJ3 (injection #3 - training of the attendants) was introduced. With the existing external constraint and an predictable slow increase of the demand for HBOT, it enables the staff to run a higher number of sessions than that provided at present.

3.3. How to implement the change?

1. Exploitation of the constraint:
   a) Development of a schedule for utilisation of the hyperbaric chamber (Drum).
   b) When the personnel is informed in advance about the absence of a patient (see point 2c), they notify a buffer outpatient (Rope 1) who declared to be available during the entire therapy time and is able to get to the hospital within two hours from the time he/she is informed. This patient substitutes the absent one.
   c) Each outpatient qualified for the hyperbaric treatment signs declaration that three consecutive absences without an excuse will result in removal from the list of patients, and restarting of the qualification process anew.
   d) If no outpatients are available, a hospital patient qualified for the therapy replaces the absent person.
2. Subordination of the remaining resources of the system to the constraint.
   a) Creation of quantity buffers (inpatients) and quantity/time buffers (time to get to the hospital for selected outpatients).
   b) If no outpatients are available, the laboratory uses the quantity buffer, i.e. a hospital patient qualified for the therapy.
   c) The wards where the buffer patients are hospitalised transport the patient to the chamber within 10 minutes following the notification obtained from the HBO laboratory (Rope 2). Therefore, it is possible to fill in for a late outpatient (see 2a).
   d) Session scheduling and management of buffers and queues are conducted visually, using a simple magnetic board with moveable tokens, on which post-its with medical record numbers are placed (Fig. 4). This enables identification of patients by the personnel, but not by third parties. Each session, identified by the hour it starts, has a proper number of tokens (patients). To the right of the session field there are three columns marked as: just. (justified absence), unjust.
   e) (unjustified absence) and remarks. Information about patient availability is displayed on the board on an ongoing basis.

Figure 4 demonstrates the therapy plan for a given day, and the changes introduced if needed. For example one of the patients planned for the session at 6:45 informed about his absence the day before, and the HBOT laboratory personnel contacted a patient planned for 14:45, a patient from the outpatient buffer, and corrected the schedule. Another patient planned for 6:45 did not come to the session, so the one from the hospital buffer replaced him.

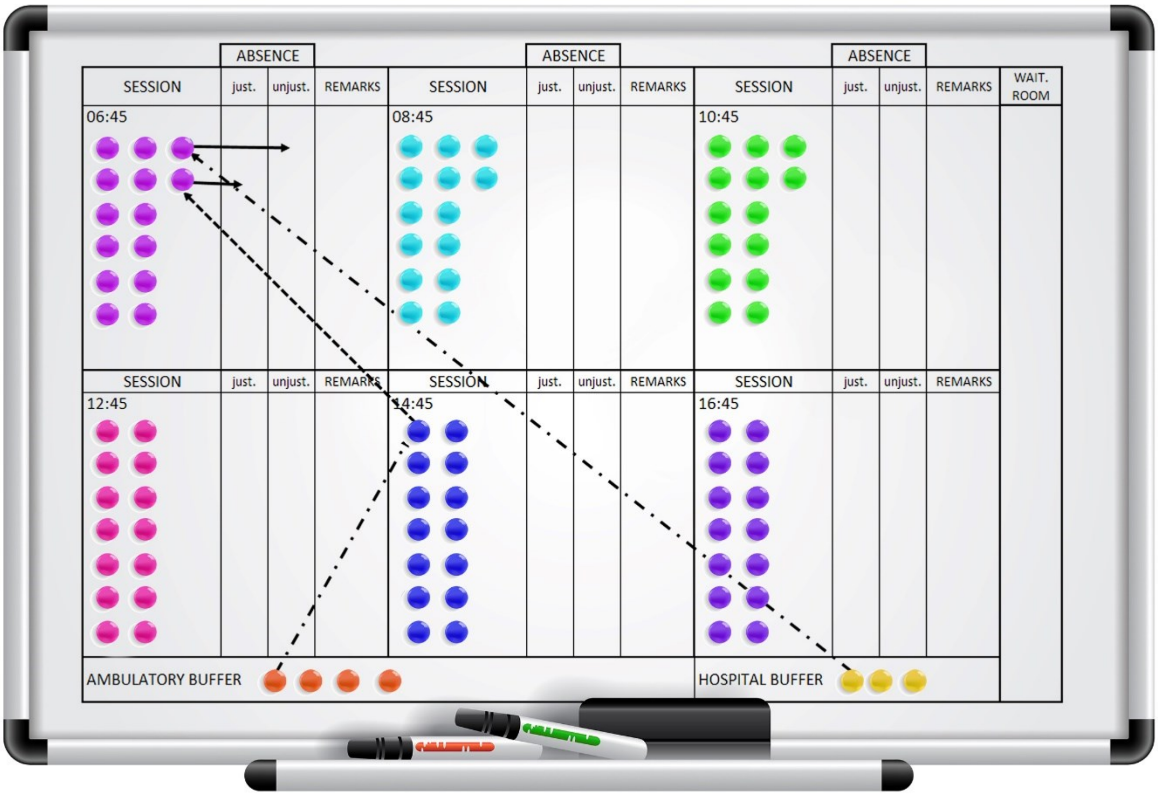

Figure 4. Monitoring table scheme – original schedule and the mechanism of substitution. Source: own elaboration.

3.4. How to measure and sustain the change?

The HBOT team monitors the number of patients on a daily basis, so any variances from the plan are immediately identified. The monitoring includes both planned and actual number of sessions, the number of absent patients, inpatient and outpatient buffer, and current use status of the buffers. This information is sufficient for the HBOT team undertaking actions on an ongoing basis. Financial reports are prepared weekly by the department of medical statistics.

The HBOT team introduced the education of patients. The information about HBOT therapy is presented in the form of brochures and films, what makes them aware of the need to participate in sessions regularly, and to meet obligatory safety requirements.

3.5. Results

The project was implemented in the period from April to October 2018. Fig. 5 illustrates the initial situation, and the results obtained between January 2018 and December 2019. Initially, both the number of planned patients and those actually participating in sessions were below the daily schedule requirement (80 patients/day).

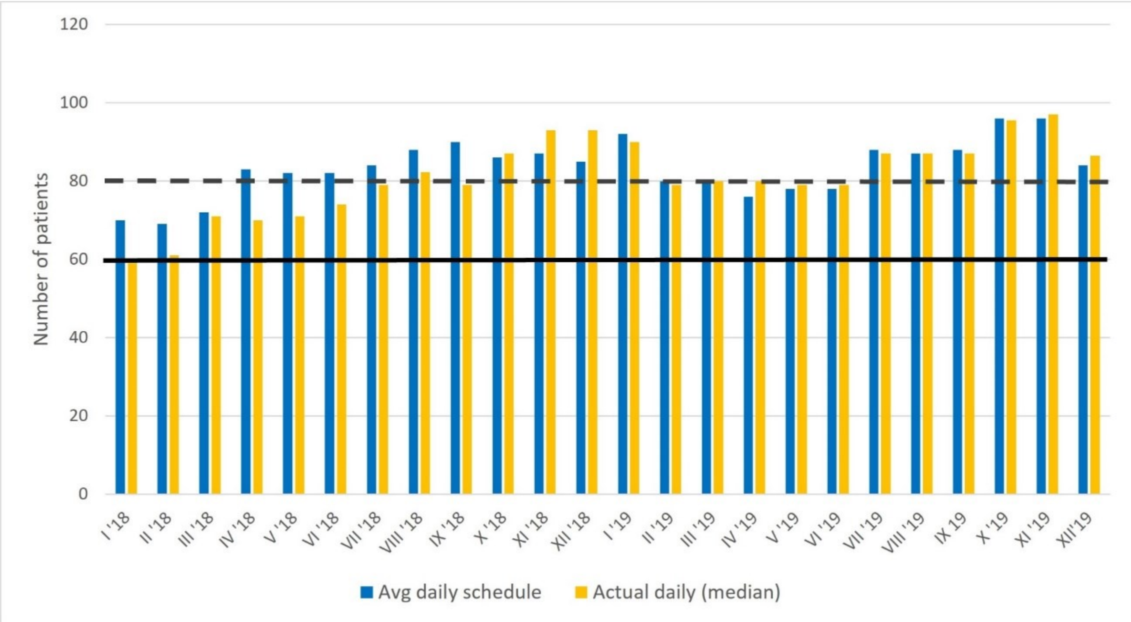

Figure 5. Actual vs. daily budget (median) 2018-2019. Solid line illustrates average daily execution before launching the project. Dashed line presents the required level as stated in the budget. Source: own elaboration.

The lower horizontal line illustrates the average number of patients per day, who actually participated in the sessions before March 2018. The target level is marked by the upper (dashed) horizontal line. Since April 2018, the daily target of 80 patients or more, if necessary, has become a standard, and actions were taken to ensure its execution, as described above. Since October 2018, monthly execution has reached the level equal to or higher than the monthly target. This made up for the shortfall, reduced the waiting time from a maximum of 24 weeks to 1-2 weeks, decreased the number of sessions, and made the working hours of the attendants predictable. The reduced waiting time for the first session in the therapeutic cycle contributed to a higher effectiveness of the treatment, and improved patients' comfort.

Table 2 presents a summary of the adverse effects identified before the project implementation, and the desirable effects achieved as a result of the implementation of Focusing Steps. It also demonstrates how the applied Focusing Steps are related to the global measures, as well as to the requirements resulting from the CQA triangle. The results achieved after the implementation of the project remained stable until 2020, with a slight tendency to increase. The flattening in February-May 2019 was mainly seasonal, and was the result of patients infections.

Table 2.
List of undertaken actions and their organisational consequences

Undesirable effects/risks before starting the project (April 2018)	Applied Focusing Steps	Desirable effects achieved after the implementation (October 2018 on)
Insufficient daily schedule execution: 1. Required no. of patients: 80 per day 2. Actual no. of patients: 60 per day	IDENTIFICATION of constraints, in order: 1. Procedural 2. External 3. Peak-time EXPLOITATION: Ensuring the use of the chamber at its full capacity EXPLOITATION/SUBORDINATION: 1. Elimination of the session exclusively for the hospitalised patients 2. Development and compliance with the procedures of co-operation with: a. Hospital wards (internal buffers) b. Outpatients (external buffers) availability and punctuality 3. Patient education	1. Daily schedule at the level of 80 patients. 2. Full chamber during sessions. Daily schedules met or exceeded. 3. Flexibility in reacting to patient deficits: improved scheduling and performance 4. No late arrivals of internal patients.
3. Long waiting queues – 20 to 24 weeks to start the therapy 4. Expenses associated with additional technical and personal costs	SUBORDINATION: 1. Buffer management ensures the chamber is used at 100% capacity during sessions 2. Reducing the number of sessions and chamber utilisation at full patient capacity reduces unnecessary costs	5. Waiting times reduced to 1 week 6. Cycle repetition ensured 7. Reduction of operating expenses (data not disclosed by the hospital)
5. Potential risk of temporary personnel deficits, reducing the number of sessions due to absences	SUBORDINATION: 3. Sustaining the controlled number of sessions prevents shifting of the bottleneck (market – hospital employees – market) 4. Training of new attendants	8. Session stability – predictable demand for attendants/day 9. No. of attendants sufficient to cover daily requirements.

Source: own elaboration.

4. Disscusion

Elimination of the previously applied approach demonstrated that the constraint was, in fact, of external nature: the current number of referrals to the chamber was lower than its working capacity. The presented case is, according to the authors' knowledge, the first one to describe the use of TOC to address a market constraint in healthcare. In for-profit enterprises, the typical solution involves intensifying of the marketing activities. In the case of publicly funded hospitals, this option is not available.

However, the presented example proves that it is possible to apply a solution other than marketing operations, which can effectively ensure full use of the public funds available to the hospital and prevent their waste. Obviously, the described approach can also be used by private healthcare providers that do not receive public funding.

Utilisation of DBR (Table 2, middle column) and the additional tools (Table 4) eliminated or significantly limited the abovementioned constraints. The targets for 2018 to 2020 were met. At the time of writing of this article (September 2021), the annual target despite the pandemic, is not threatened. The waiting time for the first session in the chamber was reduced from approximately six months to 1 week. In the case of an increased number of referrals, the hospital has the option and resources to provide additional sessions.

Table 3 presents the effect of the solutions applied on the global measures at the hospital, and on the Cost/Quality/Access Triangle. As a result of the project, all of the key measures improved.

The COVID-19 pandemic still poses a threat to the functioning of the hyperbaric chamber. From March 2020, it has seriously affected the number of sessions, which resulted both from the hospital's safety policy (only hospital patients), and the fear of potential outpatients who cancelled appointments due to the pandemic. At the beginning of 2021, when the situation has stabilised, regular sessions and the number of patients from before the pandemic were restored. The presented project still ensures the expected benefits (Figure 6).

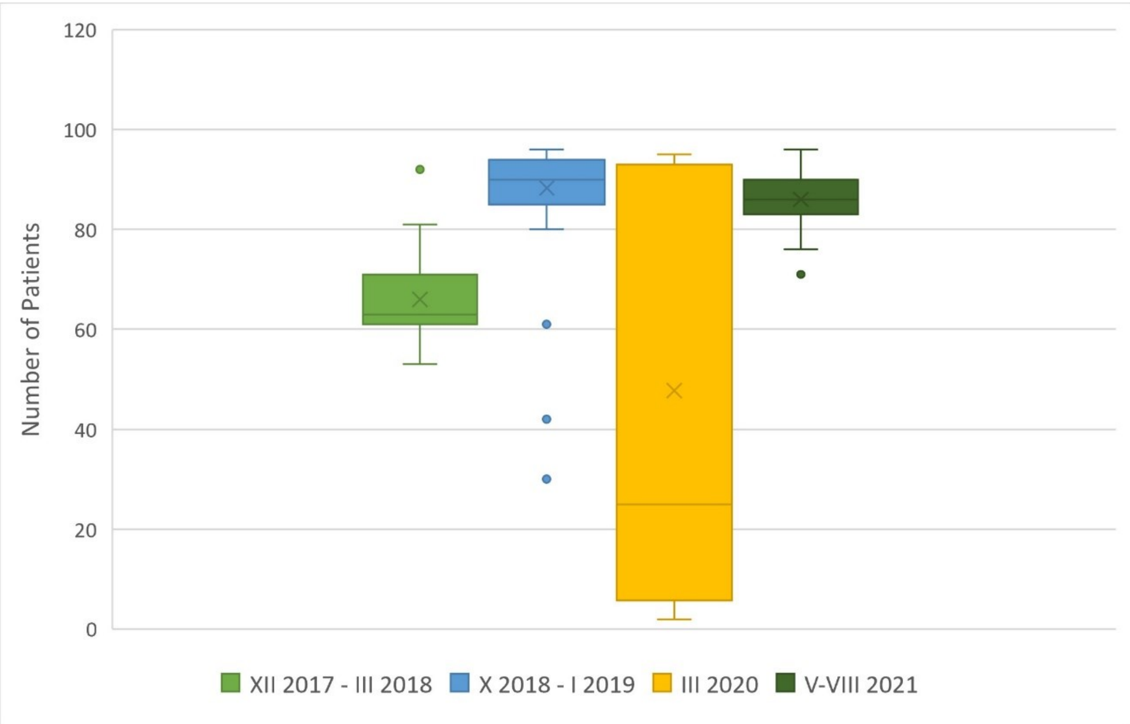

Figure 6. Distribution of patients per day in the hyperbaric chamber – comparison by periods. Source: own elaboration.

Table 3.

Applied Focusing Steps	Effect of the TOC global measures	Effect on the CQA Triangle
IDENTIFICATION of constraints: 1. Procedural 2. External 3. Peak-time EXPLOITATION: Ensuring the use of the chamber at its full patient capacity EXPLOITATION/SUBORDINATION: 4. Elimination of the sessions exclusively for the hospitalised patients 5. Development and compliance with the procedures of co-operation with: a. Hospital departments b. Outpatients availability and punctuality 6. Patient education	THROUGHPUT: Increased compared to the period prior to the project implementation: 1. by 17.5% in April – August 2018 2. by 24% in April – October 2018 3. by 43% since November 2018 (before COVID-19 pandemic outbreak) Decrease in performance in 2020 was only temporary. Current (May-August 2021) throughput remains 37% over the initial period despite continuous COVID threat RESPONSE TIME: Waiting time for the first session reduced from 20-24 weeks to 1 week DUE DATE PERFORMANCE: No effect	ACCESS: Increased access to HBO therapy for patients
SUBORDINATION: 7. Buffer management ensures the chamber is used at 100% during sessions 8. Reducing the number of sessions and chamber utilisation at full patient capacity reduces unnecessary costs 9. Sustaining the controlled number of sessions prevents shifting of the bottleneck (market – hospital employees – market) 10. Training of new attendants	THROUGHPUT: No effect OPERATING EXPENSES: Data not disclosed by the hospital DUE DATE PERFORMANCE: No effect QUALITY: Earlier treatment initiation provides better therapeutic effects	COSTS: Elimination of unnecessary personal and technical costs (data not disclosed) ACCESS/QUALITY: Reduced time to therapy; faster treatment initiation provides better therapeutic effects

Effect of the proposed solutions on the measures used at the hospital.

Source: own elaboration.

The third and fourth waves of the pandemic in Poland did not bring about as strong disruptions as the beginning of the pandemic in March 2020. The strict procedures against COVID-19 were followed at the hospital at all times. Approximately 10% of patients still cancelled their appointments, but the attendance remained at over 80 patients/day. Therefore, we may conclude that the developed management system for the hyperbaric chamber has proven also to be effective during the time of the pandemic. Importantly, the primary prerequisite was ensuring safety, e.g. through vaccination of the chamber personnel in contact with patients, and through close monitoring of the patients.

The risk due to COVID-19 still does exist, and it poses a threat to the functioning of the chamber, especially if a particularly virulent mutation, more dangerous than the previous ones, occurs. In such circumstances, the use the chamber may have to be limited; nonetheless, even then the solution in place should lead to the best possible outcomes.

5. Conclusions

The article presents an original approach to improvement of healthcare providers with the use of the Theory of Constraints and additionally, Lean Management tools. The usefulness of this approach has been verified through the project in HBOT laboratory of public hospital. Table 4 presents the tools used at individual steps of the project.

Table 4.
Effect of the proposed solutions on the measures used at the hospital

Phase	Description	Basic tools	Additional tools
I	Why change?	Analysis of the statistics of resource use Financial data analysis (based on the contract with the National Heath Fun	Hyperbaric chamber data statistics and analysis Gemba walk Direct process observation
II	What to change?	Current Reality Tree (CRT)	Gemba walk C&E Diagram
III	What to change to?	Future Reality Tree (FRT)	Brainstorming
IV	How to implement the change?	Exploit the constraint – DRUM	Schedule for the use of the chamber at its full patient capacity (kanban) Visual management Procedures for substituting empty places in the chamber (heijunka)
		Subordinate BUFFER – ROPE	Quantity buffer – outpatients Time buffer – outpatients (2 h) Quantity buffer – hospital patients Time buffer – hospital patients (10 minutes Procedures for substituting empty places in the chamber (heijunka) Visual management
		Elevate the constraint	Training for additional attendants
		Transition Tree TT	Team analysis with an aid of graphic tools
		Prerequisite Tree PT	Team analysis with an aid of graphic tools
V	How to measure an sustain the change?	Measures: • Throughput • Investment • Operating Expenses • Response Time • Quality • Due-date performance	Daily hyperbaric chamber data statistics analysis in comparison to schedule and previous periods Process observation Patient education Analysis of financial results Analysis of complaints

Source: own elaboration.

The authors analysed the causes of variations from the schedules and disturbances occurring in the HBOT laboratory with an aid of Logical Thinking Tools, and developed improvements in its operation. developed by the authors. The suggested solution is beneficial both for the patients (reduced waiting times thus faster therapeutic effects), and for the hospital (income ensured, better organisation of work and no risk of temporary personnel deficits).

The advantages of presented solution, apart from aforementioned ones, include simplicity and a stable routine in scheduling and the management of late arrivals, based on the developed tools and procedures. This approach allows the chamber to be used to its full patient capacity at all times, and prevents problems due to late arrivals of patients. Involvement of the middle-level and lower-level personnel in the decision-making process plays an important motivational role (ownership).

Theoretically, the weakness of this solution lies in the small number of hyperbaric chambers it could be applied to. However, the approach is universal enough that it may be used, with small adaptations, for any constraint found in hospitals. It also offers a general framework which can be used by non-hospital healthcare providers complaining of significant underperformance, e.g. primary healthcare service providers (Korneta, 2021).

Implementation of new projects in a hospital environment is often associated with strong resistance against the change, especially on the part of the medical personnel thus, forming the barriers for implementation (Lubitsch et al., 2005; de Souza, and Pidd, 2011; Leite et al., 2019). In 2016, the hospital's top management introduced a system which focused first on the engagement of the middle management – including medical personnel – and those directly responsible for given activities. Only afterwards was it followed by the doctors. The system lifts the burden from the higher medical personnel in the first, most demanding phase of change, and also provides convincing evidence for the effectiveness of the undertaken actions, leading to their acceptance. The solution allows not only the workload on the doctors to be reduced, but also plays an important motivational function for the staff directly involved in the process of change. It also minimises potential conflicts between doctors and management in the first phase of introducing modifications. This contributes to achieving favourable outcomes, and prevents resistance to change or prompt discouragement due to a lack of positive results.

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