HOW THE PEARL CHAIN CONCEPT CAN IMPROVE THE PERFORMANCE OF OPERATING THEATERS IN HOSPITALS: RESULTS OF AN EMPIRICAL STUDY

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Abstract

The Pearl Chain Concept is an approach which bases on a stable order sequence in production planning and control with the aim improve the efficiency. Moreover a stable order sequence in production effects positively on logistic management. The key performance indicator (KPI) pearl chain grade measures the compliance of the order sequence. KPIs like e.g. the pearl chain grade are already successfully implemented in automotive and supplier industries. On the contrary the implementation and the impact on efficiency of the Pearl Chain Concept in hospitals needs to be researched.

This article examines whether a transfer of the Pearl Chain Concept from production planning and control to operating theatre management makes sense.

There is no previous research of the use of the Pearl Chain Concept in hospitals. This article represents the initial phase of research on this topic. The research methodology is based on a deductive approach. Findings from automotive industry are analytically and empirically checked in various hospitals.

Theoretical considerations and an empirical study points out the potential of the Pearl Chain Concept in a clinical setting. The results show that the pearl chain grade is not in contradiction with the efficiency (in form of capacity utilization) of an operating theatre in hospital. Consequently, the pearl chain grade could complement, and not replace, the existing key performance indicators in hospitals e.g. capacity utilization.

Key words: Pearl Chain Concept, Pearl Chain Grade, Capacity Utilization, Hospital Management, Operating Theatre Management

1. INTRODUCTION

Surgical therapies are the essential element of a value added process in hospitals. A surgery includes a surgical performance on the patient. A surgical procedure takes place in an operating theatre of the hospital. The uptime of operating theatres is a limited resource. Moreover operating theatres are the most cost-intensive areas of a hospital. They are characterized by high material costs and a considerable deployment of high qualified hospital staff. These are the main reasons why surgical therapies are

considered as the major cost drivers of the inpatient care (Bauer & Welk, 2006, p. 78 and p.93). The strategic objective of the hospital management is to achieve the greatest possible capacity utilization for operating theatres. Consequently the capacity utilization of an operating theatre is to date one of the most relevant key performance indicators. It is calculated as the ratio from the sum of the cutting/suture time and the uptime of operating theatre (see Equation 1).

Equation 1. Capacity utilization of an operating theatre

$$\boldsymbol{C}\ [\%] = \frac{\sum_{i=1}^{n} t_{CS_i}}{t_{OT}} * 100$$
$$C = Capacity\ Utilization,$$
$$t_{OT} = uptime\ of\ operating\ theatre,$$
$$t_{CS_i} = cutting/suture\ time = t_{S_i} - t_{C_i},$$
$$t_{S_i} = date\ of\ suture,$$
$$t_{C_i} = date\ of\ cutting,$$
$$patient\ i = 1, \dots, n.$$

Source: Bauer et al., 2008, p. 693

To date the performance measurement in hospitals is strongly dominated by a cost-oriented management of the resources. An assessment from a cost perspective does not adequately describe the performance of the resource operating theatre in a hospital (Jacob & Klewer, 2013, p. 50 et seqq.).

An innovative approach for the management of the operating theatres in hospitals is the compliance with the defined pearl necklace. It's a process-oriented approaches which adjust on the value creation of a product or service. The Pearl Chain Concept is already successfully implemented in automotive and supplier industries. The implementation and the impact on efficiency of the Pearl Chain Concept in a clinical setting does not have been researched yet. Consequently, this article represents an initial phase of research on this topic.

The research question of this article is whether a transfer of the Pearl Chain Concept to operating theatre management makes sense from the point of view of efficiency. The aim of this article is to point out the possibility of a transfer of the Pearl Chain Concept in a clinical setting. The purpose is to make a contribution to a more efficient operating theatre management in future.

The following chapter 2 describes the theoretical foundations of the Pearl Chain Concept. In two sub-sections the Pearl Chain Concept in automotive industry and the adaption of the Pearl Chain Concept to operating theatres in hospitals are described. In chapter 3, the design and the results of a case study are presented. Finally, the conclusion incudes aspects like interpretation of the results and suggestions for further research.

2. THEORETICAL FOUNDATIONS: PEARL CHAIN CONCEPT

The Pearl Chain Concept (also Pearl Necklace Concept) has established itself as a production planning and control instrument. In general a so-called "pearl necklace" is defined as a target sequence of pearls in a chain. In particular a pearl necklace can

represent an order sequence of goods or services to be produced. In automotive manufacturing a Pearl Chain Concept aims at the physical maintenance of a defined target sequence at the beginning of the production planning to the last step of the production (Meissner, 2009, p. 6 as well as Günthner et al., 2009, p. 14). "Freezing" of production sequence follows the customer commitment. A pearl necklace is based on the promised and binding delivery date of the good or service (Weyer, 2002, p. 72 as well as Klug, 2010, p. 403). In summary, a pearl necklace is defined as a customer-orientated, precisely-determined predecessor-successor relationship of work orders (Klug, 2010, p. 389). The compliance with the Pearl Chain Concept ideally increase the compliance with the delivery deadline. Consequently, the pearl chain approach helps to increase the customer satisfaction and contribute to a higher efficiency (Copaciu, 2013, p. 43).

The key performance indicator pearl chain grade measures the compliance of a determined target sequence at a specific date on a percentage basis (Meissner, 2009, p. 175 et seqq.). The pearl chain grade is calculated from the difference between "1" and the average deviation of the target position (see Equation 2). A strict compliance with the target sequence leads to an average deviation of 0% and a pearl chain grade of 100%. In case of an average deviation higher than "1" the pearl chain grade is equal "0".

Equation 2. Pearl Chain Grade

$$\textit{Pearl Chain Grade}\,[\%] = \left(1 - \left(\frac{1}{n}\sum_{i=1}^{n}|dot_i|\right)\right) * 100$$

$$if\ \left(\frac{1}{n}\sum_{i=1}^{n}|dot_i|\right) < 1;$$

$$\text{otherwise } Pearl\ Chain\ Grade = 0;$$

$$dot_i = \textit{deviation of the target position;}$$

$$work\ order\ i = 1, \ldots, n.$$

Source: Schröder & Tomanek, 2015, p. 130

2.1. Pearl Chain Concept in Automotive Industry

The automotive industry nowadays is characterized by a steadily increasing number of models, variants and equipment options. This continuous development leads to a raise of the complexity. In order to manage this complexity successfully many car manufacturers are making use of the Pearl Chain Concept (Lehmann & Kuhn, 2018, p. 537). Moreover, this concept offers also further opportunities for supplier and customer relationship. Through the Pearl Chain Concept suppliers can really rely on volumes and sequences. On the customer side, orders can be changed even some days before the start of the production (Klug, 2006, p. 188). According to the Pearl Chain Concept an exact production sequence is fixed usually 5–7 days before the assembly by defining a so-called "frozen zone" (Wagner & Silveira-Camargos, 2012, p.55). Thereafter an order sequence according to the pearl chain is transferred to the suppliers. Changes from the customer are during the frozen zone are no longer readily possible. The compliance of the exact production sequence forces discipline during the executing of production. Manufacturing steps can be separated by sorters.

Sorters have the task to restore the pearl chain after a batch production (e.g. in a pain shop). For the measurement of the pearl chain grade measurement points and a sequence monitoring has to be installed (Unger & Teich, 2009, p.116-117).

Since 1997 the production of the Mercedes-Benz A-Class in Rastatt is planed according to the Pearl Chain Concept (Weyer, 2002, p. 106). Meanwhile, the implementation of the Pearl Chain Concept to other manufacturers in automobile industry has progressed rapidly. Porsche plant in Zuffenhausen defines a target sequence at the beginning of the construction of a carcass. According to their own declaration the pearl chain grade at the end of the assembly is 99% (Kahmeyer, 2002, p. 52). In case of Audi, the Pearl Chain Concept is an element of the "new logistics concept". The Audi production in Neckarsulm serves as a reference plant for the implementation of the Pearl Chain Concept across the Volkswagen-Group (Seemann, 2015).

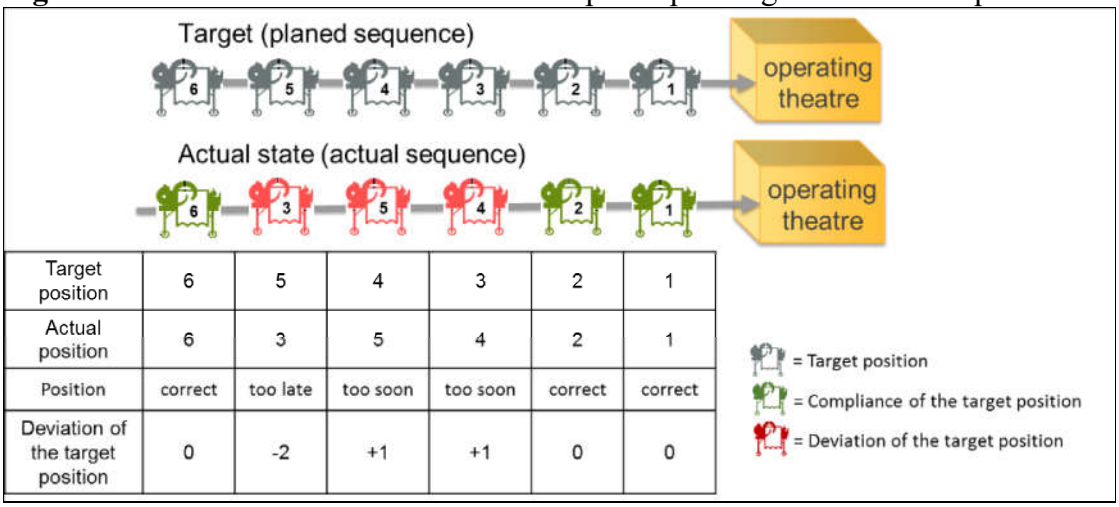
Applications of the pearl chain approach in the automotive industry showed that a stabile order sequence leads to an optimization of the production. An early order planning (taking into account relevant production restrictions) aims at a high capacity utilization and provides a continuous production flow (Copaciu, 2013, p. 43). Furthermore, heeding the Pearl Chain Concept leads to a stabilization of the information and material flow (Klug, 2010, p. 401). A "calmed" production process affects positively to all involved actors of the value creation (Copaciu, 2013, p. 43). The Pearl Chain Concept is an adapted strategy that helps to ensure the aims of lean production. Several Research studies showed that the lean approach is a key to growth and survival in times of global competition and fast changes (Unger & Teich, 2009, p.120).

2.2. Transfer of the Pearl Chain Concept to Operating Theatres in Hospitals

On the contrary to the automotive industry, hospitals are categorical service companies. For this reason, simply copying the Pearl Chain Concept from the automotive industry to clinical service is not success-promising. Moreover, taking into account the framework conditions in hospitals, a transfer of the Pearl Chain Concept to operating theatres is the most expedient solution.

The adaption of the Pearl Chain Concept bases on the idea of stable patient sequence in an operating theatre at a surgery day. It aims at a high patient satisfaction through a reliable planning. Patients represents the pearls in chain to be operated. The target positions are defined a day before the surgeries. On the day of surgery the actual position is measured. Finally, the target and actual position are brought into connection by calculating the deviation (see Figure 1). Based on the compliance or rather the deviation of the target positions a pearl chain grade can be calculated. In case of the example in Figure 1 the pearl chain grade is equivalent to 33%.

Figure 1. Transfer of the Pearl Chain Concept to operating theatres in hospitals



Target position	6	5	4	3	2	1
Actual position	6	3	5	4	2	1
Position	correct	too late	too soon	too soon	correct	correct
Deviation of the target position	0	-2	+1	+1	0	0

Source: Schröder & Tomanek, 2015, p.134

A pearl chain grade equal to 100% will be always reached when only a single surgery is planned and realised. A deviation of the target position is practically excluded. Only exception is in case of a surgery suspension. Then the pearl chain grade drops to 0%. The key performance indicator pearl chain grade can only take the values 0% or 100%. The more surgeries are planned in a period, the more deviations of the target position are possible. The probability of swirls within the target sequence rises. The degree of the pearl chain grade can take the values between 0% and 100%.

Applications of the pearl chain approach in the automotive industry imply a high capacity utilization in production. A transfer of the Pearl Chain Concept to operating theatres in hospitals requires a verification of the correlation between the pearl chain grade and the capacity utilization. The capacity utilization of an operating theatre is characterised by the proportion of the cutting/suture time within the available uptime. When just a single surgery is planned and realised, then a high capacity utilization only can be ensured by a long duration of the surgery. With regard to a high capacity utilization, a short duration of a surgery forces the operating theatre management to increase the number of planed surgeries in a period. A focus on the key performance indicator capacity utilization accepts the fact that a high capacity utilization can lead to swirls within the target sequence. Swirls, in turn, can affect negatively on the patient satisfaction based on a promised and binding surgery date.

In summary, based on theoretical considerations the pearl chain grade can be ignored by an operating theatre management for the benefit of a higher capacity utilization. Conversely, an operating theatre management can downgrade the capacity utilization for the benefit of a higher pearl chain grade. The decision how to asset the pearl chain grade in the context of the capacity utilization depends finally on the strategic orientation of a hospital.

The theoretical considerations described above leads to drawn up the following two hypotheses:

(H1) A low capacity utilization encourages a high pearl chain grade.

(H2) A high capacity leads to swirls within the target sequence. The pearl chain grade drops.

3. CASE STUDY

An empirical case study in the following section evaluates the drawn up hypotheses H1 and H2.

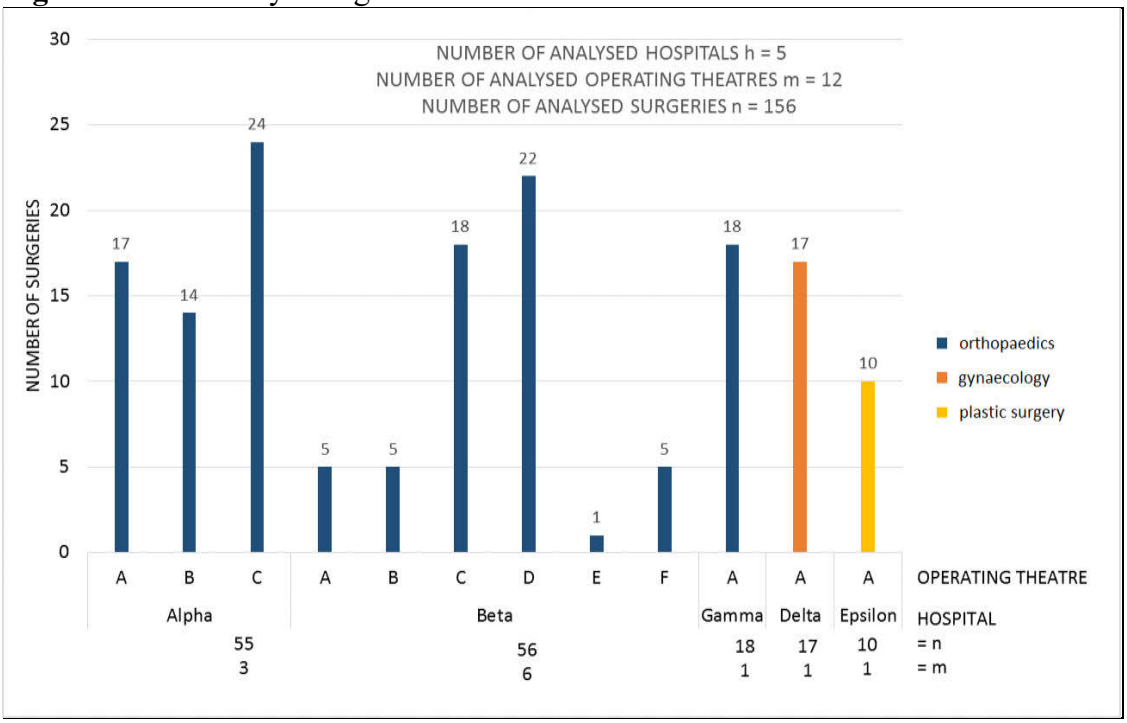
3.1. Design

On the base of literature review, the Pearl Chain Concept hasn't been never before applied to operation theatres to date. For this reason, the surveyability of a pearl chain grade in a hospital setting was checked by a preliminary study. The date acquisition of the preliminary study based on multi-moment observation in a chosen hospital. Furthermore, the results of the activity sampling procedure served to prepare a questionnaire for the main case study. The questionnaire covers queries to determine the capacity utilization and the pearl chain grade of a hospital theatre for a said time interval.

The implementation of the case study was carried out to five hospitals in Germany. For data protection reasons, the names of the hospitals are anonymised. To reach a comparability of test results, the scope of the case study are operating theatres with a low degree of emergency cases. Due to different hospitals structures, the case study includes different departments. In detail, the study covers the following participating departments: orthopaedics, gynaecology and plastic surgery. The data record takes place simultaneously in the analysed hospitals for a time interval of five working days. Due to different department structures, the number of operating theatres as well as the number of analysed surgeries in an operating theatre vary. In hospital alpha has been analysed the department of orthopaedics which includes three operating theatres. During the analysed period of five days 55 surgeries were performed. The department of orthopaedics in hospital beta includes six operating theatres. During the analysed period of five days 56 surgeries were performed. Hospital gamma also focus on orthopaedics. This department performed 18 surgeries in one operating theatre. In hospital delta has been analysed the department of gynaecology. During the analysed period of five days 17 surgeries were performed in one operating theatre. In hospital epsilon has been analysed the department of plastic surgery. Within five days 10 surgeries were performed in one operating theatre.

With regard to the case study, the number of analysed operating theatres is 12. The number of analysed surgeries is 156 (see Figure 3).

Figure 3. Case Study Design

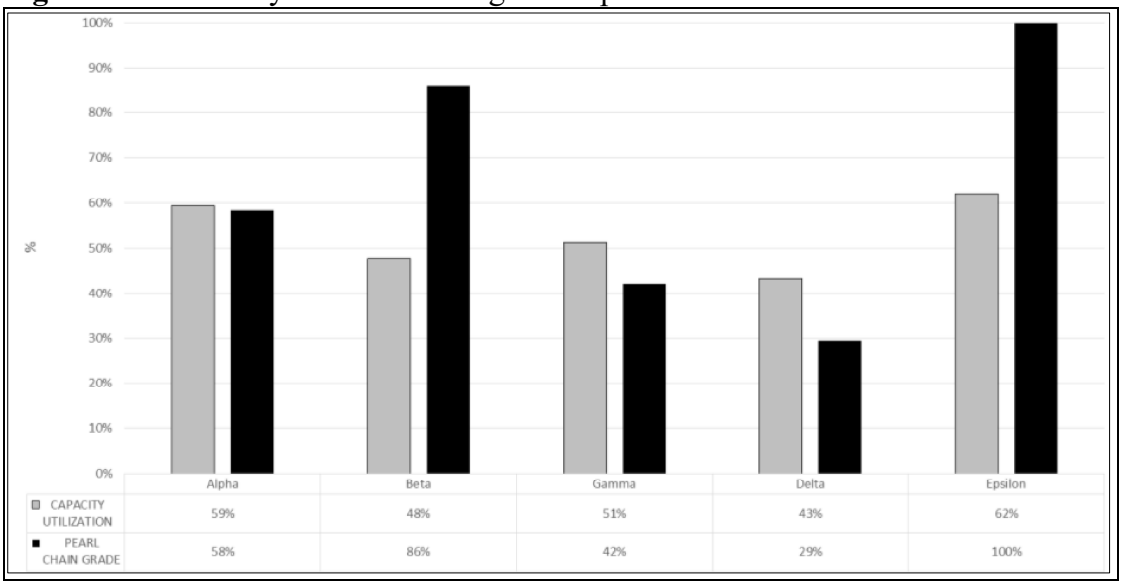


Source: Tomanek, 2018, p.100

3.2. Results

In the case study, the averaged capacity utilization ranges cross-hospital between 43% and 62%. The pearl chain grade varies between 29% and 100%. (see Figure 4). In detail, hospital alpha has an averaged pearl chain grade of 58%. The averaged capacity utilization of alpha is 59%. Beta's averaged pearl chain grade is 86% while the averaged capacity utilization corresponds to 48%. On the contrary, in hospital gamma the pearl chain grade of 42% is lower than the capacity utilization of 51%. The same situation is in hospital delta where the averaged capacity utilization corresponds to 43% and the averaged pearl chain grade is 29%. This is the lowest averaged pearl chain grade as well as the lowest averaged capacity utilization of the case study. Epsilon is the only hospital with a "perfect" pearl chain grad of 100%. The averaged capacity utilization of epsilon corresponds to 62% which is the highest value of this key performance indicator in this case study. The characteristics especially of hospital gamma and epsilon an initial indicators for a positive correlation between pearl chain grade and capacity utilization. The drawn up hypothesis that a low capacity utilization encourages a high pearl chain grade is rejected by gamma. The second hypothesis that a high capacity leads to a drop of pearl chain grade is rejected empirically by epsilon.

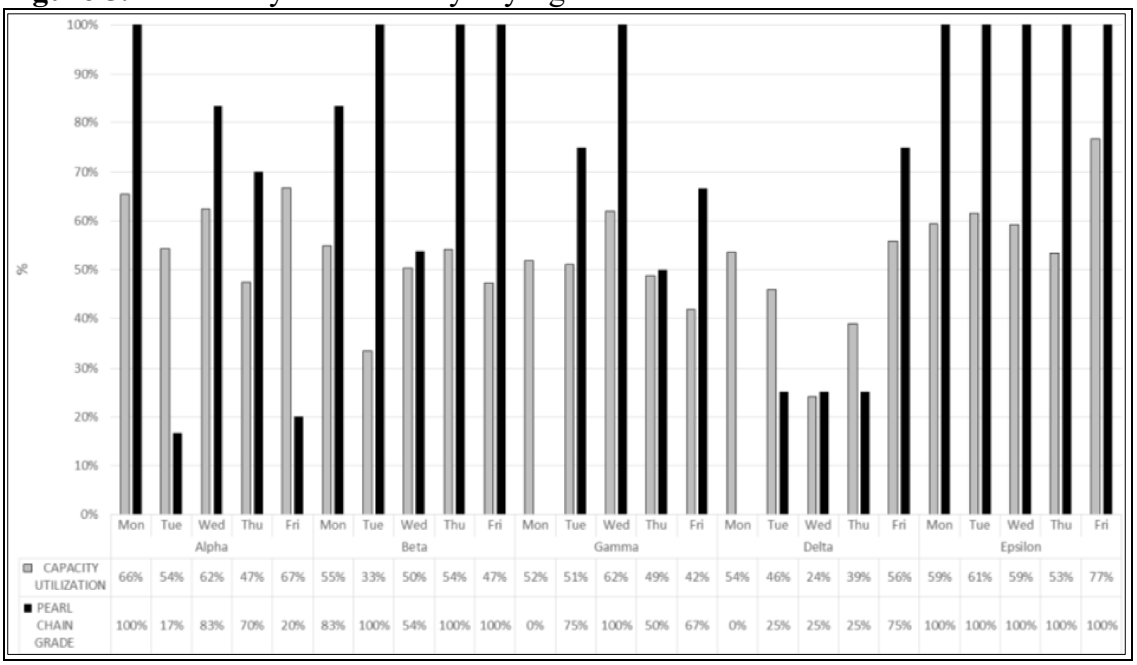
Figure 4. Case Study Results - averaged comparison



Source: Own research

Based on day key figures, the capacity utilization ranges cross-hospital between 24% and 77%. The evaluation of the data showed that in this perspective the pearl chain grade varies stronger than the capacity utilization. The analysed pearl chain grade moves cross-hospital in the range of a minimum level of 0% and a maximum level of 100% (see Figure 5).

Figure 5. Case Study Results - day key figures



Source: Own research

Day key figures in hospitals are more suitable for determining a correlation between two performance indicators than an averaged comparison. The causal link

between capacity utilization and pearl chain grade can be analysed by a correlation coefficients (see Equation 3). A correlation coefficient describes how strong a relationship is between two variables. A correlation coefficient has a value between -1 and 1.

A positive correlation coefficient means that for every increase of variable one, there is an increase of variable two and vice versa. It also means that for every decrease of variable one, there is a decrease of variable two and vice versa. A correlation coefficient between 1 and 0.7 indicates a strong positive relationship. A correlation coefficient between 0.7 and 0.3 indicates a weak positive relationship.

A negative correlation coefficient means that for every increase of variable one, there is a decrease of variable two and vice versa. A correlation coefficient between -1 and -0.7 indicates a strong negative relationship. A correlation coefficient between -0.7 and -0.3 indicates a weak negative relationship.

A correlation coefficient between -0.3 and 0.3 means that two variables aren't related.

Equation 3. Correlation coefficient

$$\boldsymbol{Corr}\ (\mathbf{X}, \mathbf{Y}) = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

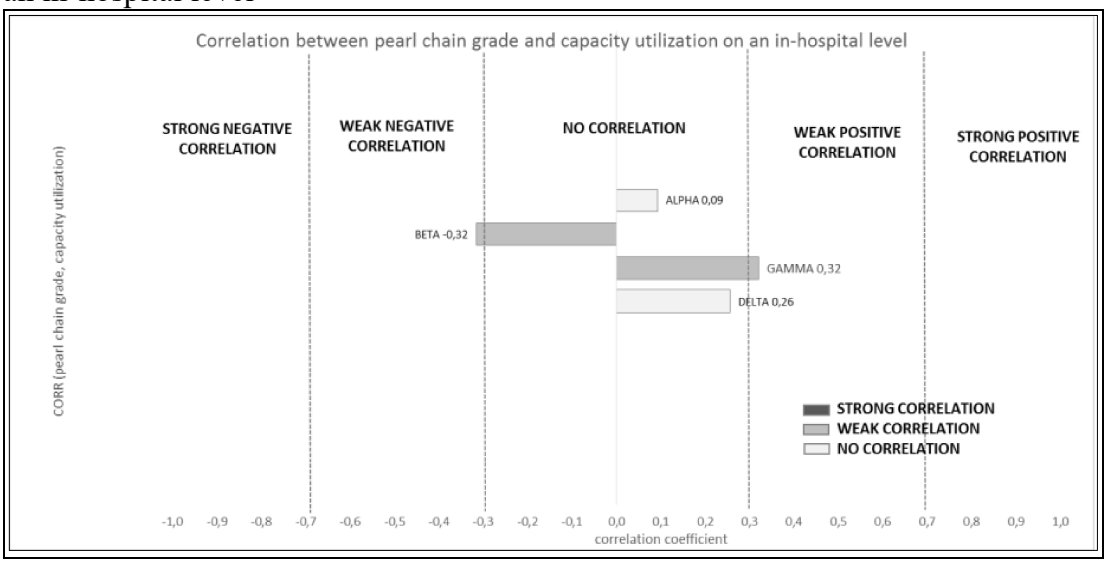
$$where\ \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i\ and\ \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

Source: Kronthaler, 2016, p. 72

Based on the results of the case study, a cross-hospital correlation coefficient between capacity utilization and pearl chain grade is 0.33. It represents a weak positive correlation which implicates that a pearl chain grade has a weak positive impact on capacity utilization and vice versa. On a cross-hospital level, the hypothesis H1 that a low capacity utilization encourages a high pearl chain grade is rejected empirically. The hypothesis H2 that a high capacity leads to a drop of pearl chain grade is also rejected empirically on a cross-hospital level.

A holistic cross-hospital evaluation ignores the unique environment and structure of each hospital. For this reason it is expedient to evaluate in-hospital correlations between capacity utilization and pearl chain grade (see Figure 6). Based on the data of the case study, hospital alpha and delta have correlation coefficient between -0.3 and 0.3. This means that in hospital alpha and delta the day key figures capacity utilization and pearl chain grade aren't related. In hospital gamma the correlation coefficient between pearl chain grade and capacity utilization indicates a weak positive relationship. A positive correlation rejects the drawn up hypotheses H1 and H2. This is contrasted with hospital beta where the correlation coefficient between pearl chain grade and capacity utilization indicates a weak negative relationship. This confirm the drawn up hypotheses H1 and H2. A correlation coefficient for epsilon cannot be calculated due to the reason of a constant pearl chain grade of 100% every day.

Figure 6. Correlation analysis between pearl chain grade and capacity utilization on an in-hospital level



Source: Own research

Summarizing the analysis on an in-hospital level, the hypothesis H1 that a low capacity utilization encourages a high pearl chain grade is neither confirmed nor rejected empirically. The hypothesis H2 that a high capacity leads to a drop of pearl chain grade is also not neither confirmed nor rejected empirically on an in-hospital level.

4. CONCLUSION

On a cross-hospital level, a negative correlation between pearl chain grade and capacity utilization cannot be proved empirically by the analysed hospitals. This result shows that the pearl chain grade is not in contradiction with the efficiency (in form of capacity utilization) of an operating theatre in hospital. Consequently, the pearl chain grade could complement, not replace, the existing performance measurement. By an in-hospital correlation analysis, it is also showed that in single hospitals there exist a negative correlation between pearl chain grade and capacity utilization. Due to diversity of the analysed hospitals it is not possible to exclude that soft factors could influence the results.

Based on empirical results, it is not practical to transfer the Pearl Chain Concept in general to operation theatres in hospitals. Rather, it is expedient to make a specific recommendation for a hospital taking into consideration influencing factors like department, emergency rate, etc. Only then the Pearl Chain Concept can improve the efficiency of operating rooms in theatres and contribute to at a higher patient satisfaction through a reliable planning.

The present paper is based on an extensive qualitative research. Due to the number of only five analysed hospitals the correlation analysis makes no claim to an insufficient statistical power of the case study. This is more a cautious approach to the

use of the Pearl Chain Concept in hospitals. This paper represents the initial phase of research on a topic that has been not previously analysed.

From a scientific point of view, it is expedient to establish a higher sampling rate to confirm or refute the results of the described case study. It is also important to identify by addition research which and how soft factors influence on the pearl chain grade in hospitals.

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