The design and implementation of a WLC system incorporating time buffer signalling: an action research study

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Abstract

The purpose of this paper is to explore the particular issues concerning the design and implementation of workload control (WLC) in the management of a customised high touch time MTO (Make to Order) environment involving rotary moulding. The system embraces key workload control features, including order acceptance and controlled release incorporating time buffer management for priority control. The design and implementation over a two year period has offered opportunity to determine the applicability of S-DBR based WLC. The resulting system is integrated with a Sage ERP system and specifically designed to support operational decision making whilst providing visibility to the owner manager.

Keywords: workload control, S-DBR, time buffer management

Introduction

Time buffer management is closely associated with the control of Make to Order (MTO) production environments where the touch time is relatively small compared with the overall lead time in what is termed simplified Drum-Buffer-Rope. However, this signalling tool needs to be redesigned when dealing with environments characterised by high touch time. This paper explores this development in the context of WLC concepts with a particular focus on control using time buffer management and planned-load, an area that is not well developed in the WLC research field. This paper is organised as follows. The literature review section begins by providing an introduction to the WLC concept. Using the WLC lens developed, the recent production planning and control (PPC) mechanism introduced by Theory of Constraints (TOC), known as Simplified Drum-Buffer-Rope (S-DBR) is being critically reviewed to explicitly compare WLC and S-DBR. This is followed by a discussion on the research approach adopted to apply S-DBR in a small MTO manufacturing company. In the finding section, implementation issues and adaptation of the generic S-DBR design to the contextual environment is discussed. This paper concludes by highlighting the contribution of this paper and possible direction for future research.

Workload control (WLC) concept

WLC originates from the idea of input-output control in as early as the 70s (Wight, 1970) where job input into the production system has to be controlled and limited according to the production output capability. Over the years, WLC has been developed and is considered a leading production planning and control (PPC) solution for make-to-order (MTO) companies. WLC has become a generic umbrella term which includes research strands related to order review and release (ORR) method, input/output control (I/OC), load oriented manufacturing control (LOMC), and the integration of various ORR rules to control workload (ORR WLC) (Thurer et al., 2011). The fundamental principles underpinning WLC is summarised by Stevenson et al. (2011) as following: (i) Total work input rate is controlled in accordance with the output rate; (ii) Amount of WIP has to be explicitly controlled; and (iii) Throughput times has to be stabilised to provide reliable product/service to customer. Generally, there are three control points in WLC: ‘job entry’, ‘job release’, and ‘priority dispatching’, as shown in *Figure 2* below (Land and Gaalman, 1996). Various WLC rules are introduced at these points to reduce lead time and work-in-process (WIP), increase throughput and due date performance (DDP), and introducing buffers to protect production system against variabilities and uncertainties (Bergamiaschi et al., 1997; Fredendall et al., 2010; Thurer et al., 2012). A detailed account on the development of WLC (from 1980 to 2009) is reviewed by Thurer et al. (2011) from four perspectives: conceptual, analytical, simulation, and empirical, and is divided into pre-2000 and post-2000. From the review, it is evident that the LUMS (Lancaster University Management School) is the main theoretical approach adopted post-2000. In addition, its latest LUMS COR (Lancaster University Management School Corrected Order Release) has been advocated as the best order release solution (Thurer et al., 2012; 2016).

The salient feature in LUMS WLC is the addition of DSS (Decision Support System) where it has the underlying concept of Hierarchical Backlog Control, as shown in *Figure 2* below (Stevenson, 2006). The main purpose is to enable quoted delivery due date, reliable due date, and job release date to be determined based on loading and available capacity. Associated decisions such as negotiation or re-negotiation of delivery dates, prioritisation of job, or activation of buffer capacity can be made accordingly. This is well summarised by Stevenson (2006) into four main components: (i) Customer Enquiry, (ii) Job Entry, (iii) Job Release, and (iv) Shop Floor Control. Detailed equations and necessary data information to be collected to facilitate calculation can be found in Stevenson (2006), Hendry et al. (2013) and Huang (2017).

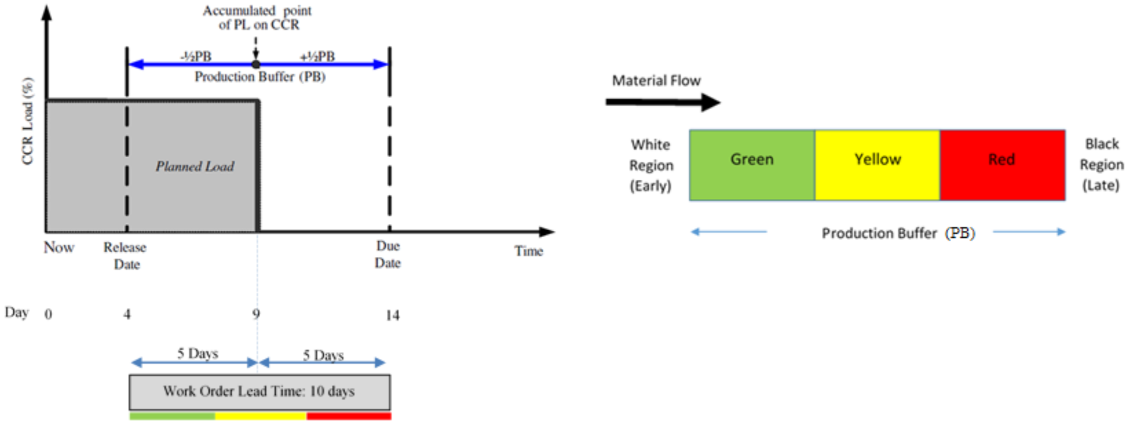
S-DBR: beyond ‘bottleneck’

Simplified Drum-Buffer-Rope (S-DBR) is a further development of Drum-Buffer-Rope (DBR) (for details, refer to Mabin and Balderstone (2003), Gupta and Boyd (2008)) proposed by Schragenheim and Dettmer (2000) which targets the make-to-order (MTO) manufacturing environment. Its conceptual details are well described in Schragenheim and Dettmer (2000), Schragenheim et al. (2009) and Schragenheim (2010). The order release concept in S-DBR (and its predecessors DBR or OPT (Optimised Production Technology (OPT))) has often been referred to as ‘bottleneck’ mechanism in WLC related research (Bergamaschi et al., 1997; Fredendall et al., 2010; Roderick et al., 1992) or theory of bottlenecks in operations management (Boer et al., 2015). While the concept of ‘*bottleneck*’ has been introduced in practitioner world through OPT in late 1970s, in WLC, it was first introduced as a job release mechanism known as ‘*Starvation Avoidance*’ by Glasse and Resende (1988). Since then, attempts have been made to compare ‘bottleneck’ based DBR and ‘aggregate’ based WLC. Using conceptual arguments, Fry (1990) argued that in the event where there exist a significant bottleneck within a system, performance of DBR is more significant. However, in the case where there is no significant bottleneck, WLC will outperform DBR. This conceptual argument is further supported by Roderick et al. (1992) through simulation, where DBR shows a better performance. Both of these input control methods have been described by Enns and Costa (2002) as the '*Bottleneck Strategy*' and the '*Aggregate Strategy*'. They highlighted the two perspectives to study input control: '*Capacity Constrained*' or '*Market Constrained*'. The former happens if market demand is higher than internal resource capacity, whereas the later happens if internal capacity is higher than market demand. For the former, release is controlled by monitoring the bottleneck loading whereas the later monitors the shop load. This perspective is in-lined with the assumptions used in DBR and S-DBR. In DBR, the assumption is that market demand is higher than internal resource capacity. However, as argued by Schragenheim and Dettmer (2000), the market is normally the dominant constraint, and proposed the use of S-DBR. In the simulation study performed by Enns and Costa (2002), it is found that '*Bottleneck Strategy*' out performs '*Aggregate Strategy*' in high routing variability shop floor. Their simulation demonstrated better performance if a priority dispatch rule is assigned, for example, higher priority is given for work which requires higher processing time at the bottleneck resource. However, in their research design, orders which do not require bottleneck resource are released immediately onto the shopfloor. This resulted in high WIP for non-bottleneck resources. This has ignored the DBR practice, where the release of non-bottleneck resource work orders are controlled by '*Shipping Buffer*' through '*Buffer Management*'. In a review done by Sabuncuoglu and Karapinar (1999), DBR solutions have been categorised as a 'bottleneck' dependant release mechanism with no due date information utilised. On the contrary, 'due date' is essential information in the DBR solution using '*Buffer Management*'. From the above it is evident the DBR concept has been over simplified reducing it to a '*bottleneck*' rule, which only refers to the '*Constraint Management*' part of the DBR solution. The '*Buffer Management*' part of the solution has been largely ignored.

This section will introduce S-DBR and its mechanisms through the four main components of WLC highlighted above. However, it is necessary to precede the discussion with a brief introduction to the 'Plan Load (PL)' and 'Buffer Management (BM)' concepts in S-DBR. Under MTO strategy, due date (DD) adherence to market demand is a critical order winning criteria for MTO companies. It is the 'market' which will ultimately determine the 'pace' of the production system. Thus, it is natural for S-DBR to consider the 'market' as the 'drum' which sets the 'pace' and exerts the 'pulling' force in the system (Goldratt and Cox, 1984; Hopp and Spearman, 2004; Schragenheim and Dettmer, 2001). Having identified the 'market' as the 'drum', it is natural to have the entire production system aligned and subordinated to the 'market'. In order to protect the promised due date against uncertainties, it is necessary to introduce a 'buffer' into the system. Inheriting from TOC philosophy, S-DBR uses 'time buffers' to protect the market DD. In order to determine a reliable DD in the pre-sales stage, and to monitor and control the shop floor to adhere to the DD in post-sales stage, S-DBR uses the concept of PL and BM.

Plan Load (PL)

According to the Theory of Constraints International Certification Organisation (TOCICO) dictionary, PL means '*The total load on a resource of all the firm orders that have to be delivered within a certain horizon of time. The time horizon used to determine the planned load is generally longer than the production buffer by at least a factor of two. The planned load is used extensively to ensure smooth flow and to make due date* *commitments that can be reliably achieved*'. PL is used to monitor potential capacity constraint resources (CCR) within the system (Schragenheim, 2010:180). It includes all the current active and in-queue jobs on the CCR, as illustrated in *Figure 1* below. By monitoring workload on potential CCR, typically not to exceed planned load, PL becomes an essential element in S-DBR as it can be used to provide delivery due date and schedule order release date. The generic S-DBR assumes position of CCR to be in the middle of the production process, thus, proposes delivery due date to be the sum of half of the production buffer (PB) plus the next available time slot on the CCR, as shown in *Figure 1* below. PB, according to TOCICO dictionary is defined as '*a liberal estimate of the amount of time required to reliably complete production of a work order*', which could be the standard industry accepted lead time. For example, referring to *Figure 1* below, if the lead time for a product is 10 days, the order due date is determined by adding half of necessary lead time (5 days) to the first available time slot on PL (day 9). Thus, the order due date will be the end of day 14 or the beginning of day 15. The raw material release date is determined by subtracting 5 days from the earliest available time slot at PL, which is day 4. This is with the assumption where under normal circumstances, all upstream work centres are able to finish the required processes and arrive at the CCR in time to be processed. The downstream work centres, with larger capacity than CCR, will continue to complete the remaining processes with 'roadrunner' attitude. The use of PL to determine order due date proactively 'smoothen' the workload at the CCR, which directly smoothen the 'flow' within the system. In addition, it reduces the risk of CCR becoming the contributing factor to any late deliveries. The other important function of PL is to monitor the workload of potential CCRs. As highlighted by Schragenheim et al. (2009 : 46), this provides visibility to management to make decision based on contextual requirements. This includes decisions on 'when' to increase capacity, decisions on whether to utilise excess capacity to fulfil win-win urgent orders, or whether a decision to increase capacity will cause other resources to become CCRs.



(a) Plan Load (PL) to determine Release Date and Due Date

(b) Buffer Management (BM)

Figure 1: Plan Load and Buffer Management in S-DBR

Buffer Management (BM)

According to TOCICO dictionary (Cox III et al., 2012), BM is a time based control mechanism with the following four main functions:

1. To *prioritise* tasks/orders based on buffer penetration/consumption.
2. To *expedite* tasks/orders that are at risk of missing promised due date.
3. To *feedback* any necessary buffer design parameters or *escalate* if requires decision making by higher management (Stratton and Knight, 2009).
4. To *target* areas and engage in ongoing improvement activities (Stratton and Knight, 2009).

The above main functions show the significant role of BM in S-DBR. It is used as a diagnostic tool to 'signal' the 'health status' of the production system (Schragenheim and Ronen, 1991; Blackstone, 2010:161). The implementation of BM for DBR is well described by Schragenheim and Ronen (1990, 1991) and Simatupang (2000). Firstly, the time buffer is divided into three 'buffer regions', represented by 'Red', 'Yellow' and 'Green'. According to TOCICO dictionary (Cox III et al., 2012), 'buffer regions' indicate priority and the need for proactive actions to avoid delays or starvation of a '*Constraint*'. Generally, each 'buffer region' is set as one third of the total buffer size. The buffer size, as recommended in TOCICO dictionary is to be half of the original lead time. However, it is highlighted that both buffer and region size has to be adapted according to contextual characteristics of process flow and product range. Other colours are used to indicate two regions outside of the 'buffer regions': orders released ahead of schedule (early release), and late orders (which usually coloured as 'black'), as illustrated in *Figure 3* below. If a job has penetrated into the Green region, it signals the job can be released into the system; the Yellow region signals a job should have been released into the system, and the Red region alerts expediting the progress and immediate release. If required, escalation to higher management for necessary decisions or action to solution will be taken. An inquiry process identifies the reasons for Red and Black penetration to target continuous improvement.

S-DBR and WLC

Based on the above discussion, this section attempts to identify the similarities and differences between S-DBR and WLC, especially in their conceptual and design level. Both are suitable PPC systems for MTO and both systems adopts a systemic approach in dealing with production flow within system. In order to increase flow, various control points are introduced to reduce WIP and at the same time increase production throughput. Both systems withhold firm work orders in a 'pool' before releasing them into the production system. This control and release decision mechanism is known as '*order review/release (ORR)*' in WLC. Whereas, it is '*Choke and Release*'. In ORR, various 'rules' have been introduced, mixed and matched to find the 'best fit' ORR through simulation. The rule categories researched mainly centred around two key elements: (i) system loading and (ii) due date adherence, which are also the focus of S-DBR: '*Plan Load*' and '*Buffer Management*'. These elements are important to both provide a reliable due date during pre-sales stage, and to determine the priority of work order after it is converted into a confirmed order in the production system. In order to protect system against variation and uncertainties, both S-DBR and WLC deploys ‘buffer’. The work order ‘pooled’ before entering production system naturally forms the first buffer to the system. In WLC, buffers are deployed to every work centre to avoid ‘starvation’ by the control of ‘Work Norm (WN)’, configured according to work centre capacity and shop floor experience. The ‘work centre’ capacity could be of a single machine or by aggregating capacity of machines with similar work process function. In S-DBR, instead of monitoring the load of every work centre, only work centres with potential to turn into critical capacity resource (or ‘*bottleneck*’) are monitored. The load at work centres includes all unfinished confirmed orders in hand which requires the usage of the work centre. Although both S-DBR and WLC have their differences, there were calls from researchers to look at using salient features from each. For example, Riezebos et al. (2003) demonstrated the use of WLC rules in solving the ‘wandering bottleneck’ issue in DBR. A more detailed review shows similarity between their proposal and S-DBR, particularly in ‘the monitoring of potential capacity constraint resources’ and ‘cumulative representation of work order processing time’. More recent works, such as Fernandes et al. (2014) and Thurer et al. (2017), have suggested ‘cross-breed’ research, particularly in adopting the simplicity and practicality in implementing DBR solution. In response to this, this paper attempts to demonstrate the similarities between S-DBR and WLC through a recent S-DBR based PPC implementation in a small MTO company, and propose the use of time buffer management to manage work order priorities. An illustration of this is shown in *Figure 2* adapted from Thurer et al. (2011).

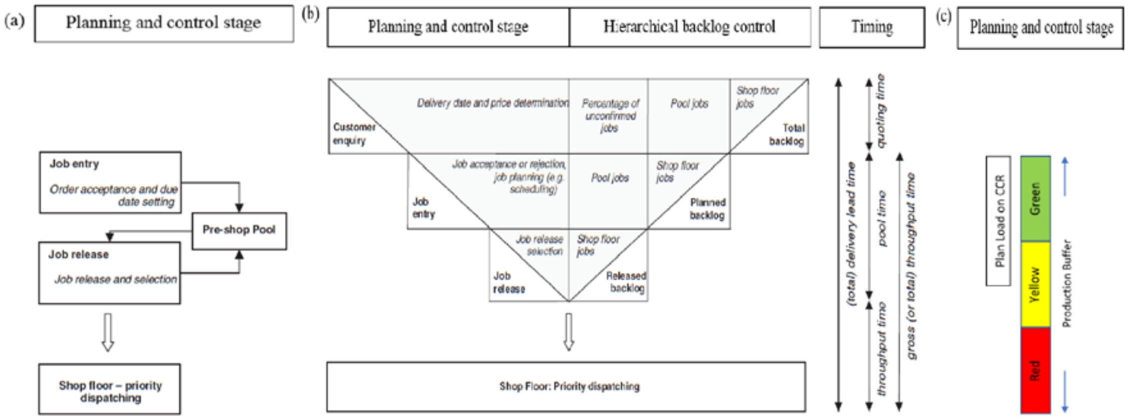


Figure 2: (a) General WLC, (b) LUMC WLC and (c) S-DBR in the three control stages
Source: Adapted from Thurer et al. (2011)

Design/methodology/approach

Having reviewed the concepts and principles underpinning Production Planning and Control (PP&C) with particular reference to make to order (MTO) and engineer to order (ETO) project environments this research utilises this knowledge in the development and testing of a hybrid PP&C system for a small SME company through a government funded Knowledge Transfer Partnership (KTP). This two and a half year (November 2015 – March 2018) project has focused on the design and implementation of PPC software that utilises the concept of variability pooling CONWIP (Hopp and Spearman, 1996), WLC (Stevenson et al.,2011) and time buffer management (TBM) (Schragenheim, 2010; Darlington et al., 2014). A macro AR cycle (Coughlan and Coghlan, 2016; Shani et al., 2010) overarches the research phases of ‘Pre-Change’ (Context and Purpose, Constructing, Planning Action), ‘In-Change’ (Taking Action), and ‘Post-Change’ (Evaluating Action). Various micro AR cycles are developed in each of these phases.

Data collection methods included maintenance of a research diary, minutes of meetings, pre and post implementation interviews and quantitative data analysis. A generic means of mapping necessity and sufficiency is used to clarify the associated assumptions underlying the adoptions of Simplified Drum Buffer Rope (SDBR) as a basis for the PPC design which incorporates TBM. This utilises abductive reasoning in developing a solution that meets the assumptions associated with the specific environment (Kim et al., 2008; Mabin and Balderstone, 2003). PPC software has now been develop and is integrated with the existing Sage ERP system which has been operational for 12 months.

Findings

The AR study followed all three implementation stages advocated by Stevenson et al. (2011). Diagnostic (6 months), theory and practice alignment (15 month), and sustain and improve (9 months). The resulting PPC system design is shown to incorporate the concept of variability pooling in both the pooling of orders prior to shop floor release and in the control of shop floor WIP embracing TBM and other WLC features. Due to the touch time being significant the TBM feature is a hybrid design due to the MTO/ETO characteristics of the manufacturing process. The order acceptance and shop floor release incorporates a load control system that utilises features from both these PPC environments which will be discussed in detail. The system has been readily accepted by the shop floor and office staff who now use it to support the setting of promise dates and priority planning enabling the owner manager to delegate but maintain oversight.

(i) Identify potential critical capacity resources (CCR)

In the company the potential CCR is located towards the beginning of the production process, known as WC_1. This CCR consists of heavily shared machine and skilled operators. Although subsequent work centres might experience occasional ‘peak’, these are considered ‘mirage’ CCR, as the capacity could be easily increased due to the workers are crossed functionally trained. In addition, these work centres are labour intensive. Loading of WC_1 is monitored without detailed scheduling (as shown in *Figure 1* above). Planned Load (PL) at CCR is calculated by summing all confirmed work orders requiring WC_1 but yet to be processed by WC_1 as depicted by equation 1 below.

Equation (1):

$$PL_{total} = \sum_{i=1}^{n} PL_{\mathrm{wo}i}$$

where $PL_{\mathrm{wo}i}$ is processing time needed for work order number i at potential CCR

(ii) Buffer Management (BM)

Priority of each work order is determined as follow. Firstly, remaining touch time (the actual processing time) for each work order is determined and summed.

Equation (2):

$$t_{touchtime} = \sum_{i=1}^{n} t_{\mathrm{wc}i},$$

where t is the remaining processing time at work centre i.

Subsequently, percent buffer penetration (BP) is determined using Equation 3.

Equation (3):

$$\%BP = \frac{t_{touchtime}}{t_{remaining}} \times 100\%$$

where, $d_{available}$ is the first available time slot of CCR; $t_{touchtime}$ is the total remaining processing time from Equation 2 and $t_{remaining}$ is the time remaining from today till due date. Work orders with higher %BP will have higher priority and colour coded with 'black' if over 100%, 'red' if between 67% - 100%, 'yellow' if between 33% - 67%, 'green' if between 0% and 33%. Work orders below 0% is coded as 'blue', and to be 'pooled' and not to be released into system.

(iii) Determine Delivery Date and Release Date

As the assumption of S-DBR is that the touch time is insignificant, less than 10 % (Harmony, 2017), which means a product spent most of its time 'queuing' and 'waiting' to be processed. Thus, making the sequence and order of work order to be processed non-essential. However, in Company A, touch time is significant with potential CCR located towards the front of the production process, the conventional way of determining delivery date by adding half of production buffer time might not be valid. As the touch time is significant, a change in processing sequence might cause the work order to not be protected by the buffer time allocated. Thus, with reference to a proposed work by Scheinkopf et al. (2012) and the concept of TOC solution for project management, Critical Chain Project Management (CCPM), the following Equation (4) is used to determine delivery date, $d_{delivery}$. As the CCR is position at the front of the production line, the release signal is triggered by the %BP, where 'blue' represents to be 'pooled', 'green' able to be released if no more urgent work orders, 'yellow' represent the recommended zone to be released, and 'red' means the work order has to be expedited. This is represented in *Figure xxx* below, together with the main control points in WLC.

Equation (4):

$$d_{delivery} = \begin{cases} Standard\ Industrial\ Lead\ Time, if\ \%BP \leq 66.7\%\ (Yellow) \\ (d_{available} + t_{touchtime}) + 5, \quad if\ \%BP > 66.7\%\ (Red) \end{cases}$$

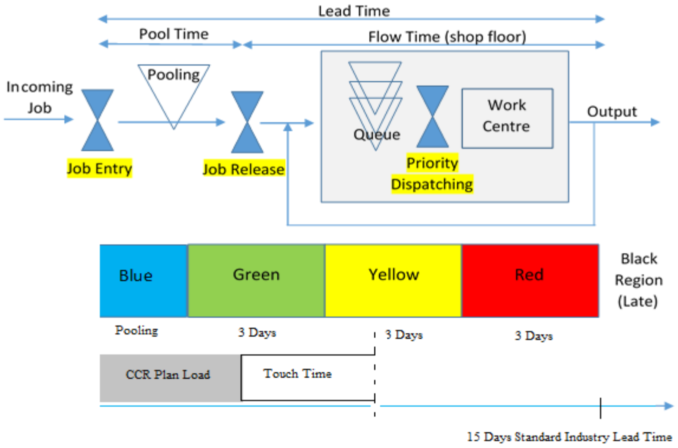


Figure 3: Modified S-DBR buffer alongside WLC control points

One year after the implementation of S-DBR, in year 2017, the company experienced the highest sales since year 2012. It was also a year where market demand distribution did not follow historical trend, where instead of seasonal, the market demand was at almost the peak throughout the year. However, the company, particularly the shop floor did not experience panic. The company was able to fulfil all orders at a due date performance of over 90% without deployment of additional shifts, which has been a tradition before this.

Conclusion

This research provides an evaluation of the design and implementation of a PPC system within a small company which enabled increased throughput with reduced operating expense and inventory. This application embraced the fundamental workload control features (Stevenson et al., 2011) but most notably demonstrating how pre-release pooling and priority control can be effectively combined through time buffer management (Schragenheim, 2010). The high processing touch time posed particular issues in the design of the pooling and buffering system that may have wider implications for similar WLC environments. The research also highlights the need for a fourth control feature in this environment, targeted continual improvement. Further research to link TBM with other signalling tools including Kanban is envisaged.

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