ABSTRACT
Production planning and control (PP&C) systems hold two conflicting requirements in tension; on the one hand achieving an optimal plan and on the other ensuring reliable execution of that plan. Demand and process variability underlie this tension and drive the need to protect the plan through the use of buffering in the form of inventory, capacity and forward load.
Simplified Drum-Buffer-Rope (SDBR) is a PP&C methodology that attempts to resolve this conflict by integrating the planning process with buffer management. This paper describes buffer management in the context of SDBR and how it has been applied within a fresh food processing company (FCF). The paper concludes that the approach is well suited to companies such as FCF where the market demands short reliable lead times in the context of high levels of variation and uncertainty. The results of this action research are discussed together with the wider issues surrounding the need to manage buffers in the context of PP&C systems.

Keywords: DBR, control, variation

INTRODUCTION
Any production plan is only as good as the data used in the planning process, which in turn is dependent on the variability and uncertainty associated with both the production process and demand. Therefore, the process of planning and control needs to take account of such instability if the plan is to be reliably achieved. However, many PP&C systems do not explicitly acknowledge variation and uncertainty in the system design and, therefore, this tension between planning and control is not effectively managed.

This paper concerns the design, development and implementation of a buffer management system in a fresh food processing company as part of a government supported Knowledge Transfer Partnership (KTP) in the UK. Existing theory regarding the application of DBR and SDBR was evaluated and selectively applied in the iterative design and implementation of a planning and control system, utilizing action research cycles.

The paper will firstly review the need to manage variation and uncertainty before introducing DBR and the more recent development, SDBR. This will be followed with details on why and how the approach was incorporated in the design and implementation of a computerised planning and control system. The paper concludes by considering the wider potential of SDBR and buffer management.
PRODUCTION PLANNING AND CONTROL

Delivery systems are characterized by dependency, variability, capacity and inventory, with the more demanding production planning and control requirements being associated with high levels of variation and uncertainty. This becomes clearer if we consider a thought experiment involving an ideal delivery system where there is no variation or uncertainty in either the process or demand.

The ideal delivery system requires no buffering

In the ideal delivery system with no variation and uncertainty market demand and capacity are perfectly matched and capacity is utilized 100%. In such a situation the functions of inventory (Hill 2005) would not be required.

- **Cycle inventory**: no set-up time losses, therefore, the product mix may be produced in any sequence without loss.
- **Buffer inventory**: no variation and uncertainty in demand or supply.
- **Decoupling inventory**: no difference in processing rates between process steps.
- **Anticipation or capacity related inventory**: no need to pull work forward as there is level demand.

A move towards this ideal state is evident in the Toyota Production System (TPS) where Ohno (1988) identifies the importance of variation and the ideal of zero inventories.

*Just-in-time means that, in a flow process, the right parts needed in assembly, reaching the assembly line at the same time they are needed and only in the amount needed. A company establishing this approach throughout can approach zero inventories. From the standpoint of production management, this is an ideal state.* (Ohno, 1988: 4)

However, it is also clear that the TPS PP&C system is dependent on relatively low levels of demand variation and uncertainty, now reflected in lean practices (Womack and Jones, 1996).

*In a kanban system, semi-processed parts waiting between processes may take the place of minimum inventory in providing a cushioning effect. Fluctuation beyond a certain magnitude, however, cannot be absorbed in this fashion, and level production becomes necessary…Obviously, thorough consideration should be given to leveling production so that such fluctuations can be prevented.* (Shingo, 1989: 187)

Managing variation and uncertainty

Shewart (1931) and Deming (1982) stressed the importance of understanding variation and its effect on delivery system performance as well as stressing the importance of reducing special and common cause variation at source. Their work on Statistical Process Control (SPC) and the concept of continuous improvement was not directly related to flow and PP&C at the time but clear conceptual links have since emerged.

*The central problem of management in all its aspects, including planning procurement, manufacturing, research, sales, personnel, accounting and law, is to understand better the meaning of variation and to extract the information contained in variation.* (Deming, 1986: 20)
Goldratt’s (Goldratt and Fox, 1986) work addressed the PP&C problem but, unlike Ohno and Shingo’s emphasis on leveling demand and reducing wasteful variation, Goldratt was primarily concerned with the need to manage variation and focus the variation reduction process. This work subsequently formed the basis of the theory of constraints, the five steps of focusing and the PP&C system entitled drum-buffer-rope (DBR) (Goldratt, 1990). Central to this approach is the concept of buffer management which encompasses the need to overtly manage inventory and capacity buffers in order to protect the delivery system from the impact of variation and uncertainty. Many applications of this methodology have been recorded (Mabin and Balderstone, 1999) and the approach continues to be developed, as in the case of Simplified Drum-Buffer-Rope (SDBR) (Schragenheim and Dettmer, 2001).

**DRUM BUFFER ROPE**

DBR is based on the need to strategically focus the planning process and uses the concept of a physical constraint in identifying what limits the throughput of a delivery system. A physical constraint is commonly defined as either the market (eg master production schedule (MPS)), or a capacity constrained resource (CCR). Market demand or a CCR, therefore, determines the pace of the delivery system (the drum) and takes the form of a detailed schedule with the material release schedule being created by applying a lead time offset (the rope).

The control phase concerns protecting the schedule at the CCR or the MPS from the impact of variation and uncertainty. This protection comes in the form of a ‘time buffer’ (Goldratt, 1990; Schragenheim and Ronen, 1991; Srikanth and Umble, 1997) in a make-to-order (MTO) environment and it equates with the lead time offset (rope) used in planning material release. The assumption is that the lead time and inventory buffer equate as the touch time in manufacturing is normally negligible when compared to the lead time.

*Traditional DBR*

DBR was originally developed in the early 1980s to support an MTO environment where the capacity limit of the CCR was used as a means of limiting order acceptance. In this environment it was common to plan products using a CCR as the drum, although it was always acknowledged that some products were constrained only by the market. Where the market is the constraint the drum is in the form of the master production schedule (MPS) and there is only one buffer involved, commonly referred to as the shipping buffer.

In the case where the CCR is the drum the schedule will specify the sequence of loading the resource to minimize set-up losses and ensure it is not over committed. In such cases there is a need to protect both the CCR and the delivery or shipping schedule (MPS) from upstream disruptions via a buffer.

*Simplified Drum-Buffer-Rope (SDBR)*

SDBR is a term derived by Schragenheim (Schragenheim and Dettmer, 2001). With SDBR the drum is assumed to always be the market demand and, therefore, there is only one rope and one buffer, the shipping buffer. This simplifying assumption is consistent with many markets where there is an implied commitment to match ongoing demand and, therefore, find the capacity required rather than refuse orders based on any capacity limits. To satisfy this assumption capacity is not permitted to constrain output and means of capacity adjustment needs to be in place. To support this need Schragenheim
(2001) developed the concept of planned load which provides a simple means of signaling when a CCR is emerging. As this feature was not eventually build into the software this is not taken further here.

BUFFER MANAGEMENT
In DBR systems the primary purpose of the buffer is to protect the system throughput from the disruptions and Schragenheim and Detmer (2001: 176) define the SDBR control as follows.

* A reactive mechanism that handles uncertainty by monitoring information that indicates a threatening situation and taking appropriate corrective action before the threat is realized.*

The schedule being protected by the buffer is termed the buffer origin and as the buffer time is consumed towards this origin the buffer penetration approaches 100%. A comparison of buffer consumption levels provides a relative priority control measure but this is further supported by dividing the buffer into three equal regions, now commonly colour coded green, yellow and red. Therefore, the regions change from green to yellow at 33% and from yellow to red at 66% buffer penetration. The significance of these regions is that the red zone signals the need for urgent action and should typically only apply to 5-10% of products as 90-95% should arrive at the schedule point without encroaching on the final third of the buffer. As 5% of arrivals are expected in the last 33% of the buffer time it is clear there is an assumption about the skewed nature of the distribution and the opportunity to manage the tail of the distribution.

There are clear parallels between buffer management and SPC (Lepore and Cohen, 1999) used in the control and improvement of quality. Deming used the tail of his variation distributions to help distinguish between special and common causes setting the signal at three times the standard deviation. Goldratt similarly uses the last third of the buffer time to signal the need to intervene and in this case expedite the product through the system. In this situation common cause variation may be considered to be the normal level of random variation. This is typically associated with process variation, set-up times and absences, whereas special cause variation is associated with exceptional sources of variation, such as major breakdowns, tooling failures or supply failure. As with SPC the buffer needs to help discriminate between common and special cause variation and not trigger unnecessary interventions, but ensure timely expediting where necessary. The size of the time buffer is a function of the capacity buffering available together with the level and frequency of disruptions. There are four functions of BM that may be summarized as follows:

- *Absorb common cause variation:* The buffer is sized with the expectation that only 5-10% of the products will penetrate the final 1/3 of the buffer (red zone).
- *Signal special cause variation in time to take corrective action:* penetration into the red zone signals the need to check and take corrective action to ensure timely delivery.
- *Monitor the overall stability of the delivery system:* Buffer penetration into the red zone that is significantly over 10% is indicative of the system becoming unstable.
- *Record and Pareto analyse repeated causes of red zone buffer penetration to target improvement:* Gathering data on the repeated causes of delay enables sources of common cause variation to be identified and targeted.

DEVELOPMENT OF A SDBR BASED PP&C SYSTEM AT FCF

Proceedings of the International Annual Conference of EurOMA, Gronegen, the Netherlands (June 08).
A SDBR based system formed the basis of a Knowledge Transfer Partnership with the task of improving the planning and control systems at FCF. The action research that followed involved several cycles of change including analysis, prototype development, final design and implementation of an operational system. There were also research findings of a more general nature that are subsequently discussed.

**Company outline**

FCF manufactures fresh “high-care”/”high-risk” vegetable and carbohydrate components for food manufacturers and supermarkets. These products are distributed directly several times per day within the UK mainland. FCF comprises several processing areas as illustrated by Figure 1. For example, raw vegetables (peppers, courgettes, aubergines, etc.) are diced prior to roasting or char grilling, which are then cooled and packed into bulk bags for distribution.

**Analysis of original planning and control needs**

Repeat orders are typically received daily with varying order levels and lead times ranging from several days to a few hours. Processing lead time is typically 6-12 hours but preparation (PREP), the main gating department, often works several days ahead of requirements to forecast. Orders are received by phone call and combined with spreadsheet data specifying yield levels to calculate bulk quantities at each stage in the process. This spreadsheet document ‘the bible’ was printed and distributed regularly and updated manually with changes communicated directly to the different departments. Any surpluses and shortages were similarly manually adjusted and communicated. A detailed spreadsheet schedule was produced daily for the roasting and char grill resources to ensure the oven times and settings were efficiently scheduled as processing at this stage must be planned for the day of shipping. As already mentioned the PREP is the major gating operation and would often work several days ahead of the delivery schedule for many of the raw materials.

The undesirable effects may be summarized as:

- WIP is too high.
- Material wastage is high (short life materials).
- Not all customers’ orders are shipped on time.
- Original plans have a very limited life.
- There are a lot of course corrections (expediting).
- Temporary staff costs are high.

**Conceptual design using traditional DBR methodology**

Figure 2 illustrates a traditional DBR design where the roasting and char grill resources would be the CCRs acting as resource drums. Material release would be determined by a lead-time offset (the rope) which represents the buffer with the buffer origin being the scheduled time on the CCR. The rope
length assumes a stock buffer exists as there is no time allowance for raw material supply in the setting of the rope. The shipping schedule is the buffer origin for the shipping buffer that applies to the CCR and non-CCR products, similarly supported by a stock buffer. In this system design products going through the CCRs would be released and prioritised via the CCR buffer up to the CCR and the shipping buffer thereafter.

**Conceptual design based on SDBR methodology**

The SDBR system would be much simpler with one shipping drum and buffer, as illustrated in Figure 2. In this system a roasting and char grill schedule would continue to be created for the operators to ensure effective utilization of these resources but this would not drive the material release. The assumption with an SDBR system is that any potential CCR will not be allowed to be active for long, but there will be a natural accumulation of orders before any limiting resource ensuring its effective utilisation. This accumulation enables flexibility in the local sequencing of work across such resources to support effective exploitation. Whereas this scheduling had previously been completed at senior management level this would be devolved to the team leader level.

**Prototype SDBR system design**

The SDBR conceptual design was chosen as it could be developed into full DBR subsequently if deemed appropriate. Additionally, although roasting and char grill currently were scheduled they were not permitted to limit the order acceptance as extended hours were used where necessary to meet daily production requirements. As part of this development stage a simpler means of order sequencing on the oven and char grill was developed and devolved to the departmental level. The prototype was developed in Excel and Visual Basic and used to test the concept and gain acceptance from users before embarking on the final system design.

**S-DBR system final design**

The final design was Web based and involved an interface with the Sage management system and the
installation of terminals on the shop floor, as illustrated in Figure 3. A typical SDBR screen layout used by management and the shop floor is illustrated in Figure 4. This figure presents the orders in buffer priority order and is colour coded to display the three buffer regions (green, yellow and red) which due to the 36 hour buffer represent 12 hours each. Where an order displays a negative buffer it indicates work has been released in advance of the planned 36 hour rope, which would normally warrant questions over why this was necessary.

If an order enters the system within 36 hours it will accrue the appropriate buffer penetration priority and, therefore, be prioritized accordingly. This may be due to late receipt of an order or yield levels being insufficient and so triggering a follow up order. As the system refreshes every few minutes such high priority orders are automatically highlighted and made visible to the current department with subsequent departments being made aware of their imminent arrival.

The system is also designed to collect data on orders regarding the order status at 33%, 66% and 100% buffer penetration with the option of recording what the order was waiting for. This data is used in SDBR systems to enable Pareto analysis of the causes of delay and thereby target improvement.

DISCUSSION

The system is now operational and there are a number of insights that have emerged from the action research cycles as briefly discussed below.

Operational and theoretical observations

- The decision to adopt SDBR supported by locally devolved scheduling of the oven and char grill worked well and it is clear the introduction of full DBR would have been inappropriate. Predicting the load on the char grill and oven has not proved an issue and, therefore, a more formal means of predicting the planned load, as advocated by Schragenhein and Dettmer (2001), has not proved necessary.
- The rope length was initially set at 48 hours, but was reduced to 36 hours at an early stage in the implementation. Due to the rope being measured in hours rather than days and there being a range of departmental shift working patterns, much of the buffer time the factory is not producing, so the rope is longer as a consequence. This contributes to red zone penetration which is greater than the 5-10% referred to in the literature (Srikanth and Umble, 1997). It is, therefore, necessary to interpret the significance of red zone penetration in the context of the shift patterns and time of day.
- One objective of the PP&C system was to help manage the release of work within the preparation department. The preparation department has reduced the inventory but works in advance of the planned release (36 hours). However, this is now visible (see Figure 4) as a negative buffer (white on the screen) and evidence to support such justification is available for management scrutiny.
- Data is collected regarding where orders are when entering the red zone, but the significance of this data is not as great as some authors suggest (Srikanth and Umble, 1997) partly due to the red zone penetration being more common with the hour based buffer and mixed shift working.
- The data needed to update the system on the shop floor was intentionally minimized to encourage ready adoption which proved successful.

CONCLUSIONS
The SDBR system has proved to be a simple and effective basis for this PP&C system and is clearly suited to markets where a CCR is not present and can be avoided. The success of this time buffering system has highlighted the need for a raw material stock buffering system which is to be designed based on similar SDBR logic.

Although the DBR and buffer management methodology has been available for many years there are still relatively few commercially available PP&C systems that embrace these concepts. Wider awareness of this simpler and more relevant methodology will hopefully result in this SDBR development being considered in both the manufacturing and service sector. There is evidence of variants on this SDBR methodology being applied in the health care (Umble and Umble, 2006; Stratton et al., 2005) and the methodology warrants closer scrutiny to establish the theoretical boundaries.
The percentage priority is calculated using the number of hours left until dispatch. Orders in white have less than 0% priority, and thus there is greater than 36 hours before they are due to be shipped.

Once completed the works order is checked off and it disappears from view, becoming enabled for the following department.

Order increases & decreases are flagged to the user.

Works orders that are currently unavailable are shown ‘greyed out’, and cannot be checked off until the previous department has confirmed that they have completed work on them.

The ‘routing’ indicates the production departments through which a product must travel. The highlighted character indicates this works order’s current position within the production chain.

Figure 4 Typical PP&C screen layout displaying orders in buffer priority order
REFERENCES