INCREASING VALUE FROM PROJECTS BY LEVERAGING LIMITED CAPACITY THROUGH THE APPLICATION OF THE THEORY OF CONSTRAINTS

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Abstract: This paper introduces the concepts of the Theory of Constraints as developed by dr. E. M. Goldratt and others. When applied to a portfolio of projects, the value that an organisation realises from successful delivery can be maximised. A new value metric is introduced that effectively accounts for the flow of money in different time periods. An approach to portfolio management that strives for maximising organisation performance, given limited organisational capacity, is also introduced. Critical Chain project scheduling and synchronising projects around the schedule of a heavily loaded (drum) resource are used as the methodology of finite capacity management that enables leveraging value with scarce resources. A new set of buffers is introduced to enable the integration of portfolio management and Critical Chain scheduling.

1. INTRODUCTION

Organisations such as professional services firms (consultancies), product development divisions of companies, research and development organisations, software developers, IT systems implementers, laboratories and engineering departments of industrial companies all supply deliverables to clients through the execution of multiple projects with limited resources.

With economies globally and locally in a state of low or zero growth, management in these organisations has to act on the assumption that markets are limited. This results in few opportunities as well as high competition in the pursuit of the opportunities. Managers have to decide which are the best opportunities to pursue, as well as how to deliver on their commitments faster and cheaper than the competitor. This has to be done with limited resources to ensure profitability.

The value acquisition process is defined in this paper as the process of opportunity initiation, development, evaluation, selection, planning, budgeting and scheduling. The value delivery process is the execution of project schedules.

In order to satisfy stakeholder needs, the organisation's management has to minimise costs and maximise value. In order to minimise costs managers have to exploit the limited delivery capability. In order to maximise value they have to exploit all the limited value opportunities. The dilemma exists primarily because external forces drive the value acquisition rate, while internal forces drive the value delivery rate, resulting in significantly different rates.

The problem is further amplified because limited resources have to be applied to the value acquisition process for their specialist skills in most of the steps of the process as well as to the value delivery process to ensure high quality fast delivery.

Before ways of solving this problem are explored, the term *value* needs to be defined.

2. DEFINITION OF VALUE

Value can be defined as the contribution to the achievement of organisational goals (Cooper, Edgett and Kleinschmidt [1]). Organisational goals are not limited to profitability, but for a for-profit organisation, this is the primary goal. Goldratt defines the goal as "generating more money now as well as in the future"[2]. Many projects that are initiated strive for the achievement of other goals such as "complying with environmental legislation" or "maximising the safety of our people" or "increasing the competitiveness of the country." In this paper, profitability is used as the primary goal and therefore value is here defined as money generated now and in the future [2].

Profitability as the only definition of value is too simplistic. It is determined from the outflow and inflow of money during a time period. When money flows as a result of the delivery of deliverables on projects, the time periods for outflows and inflows can be in different months or even years.

The concept of value should therefore include the assumption that money outflows cause the unavailability of money for other uses for a period of time and that only when money flows in is it available for use (Schlosser [3]). Value metrics such as Net Present Value (NPV), Discounted Cash Flow (DCF) and Internal Rate of Return (IRR) have been devised to account for value over time. These metrics use a discount rate (bank deposit interest rate plus an adjustment for higher risk) to transform money flows in different time periods to a common time frame (present value or future value). Goldratt [4] proposes a new value metric to do this type of accounting effectively without having to assume a discount rate.

2.1 The flush point as value metric

The foregoing arguments imply that the two variables, amount of money and timing, should be included in a value metric (as in the NPV, DCF, IRR metrics)

If a parameter of moneyXtime is introduced it can simply be accumulated. The following formula can then be applied to calculate a parameter called *flush* for each period t:

$$F_t = F_{t-1} + \sum_t M_t$$

Where F_t is the flush value at time t.
M_t is money flow in period t.
$\sum_t$ is the sum of money flows from period 1 to t.

The application of this formula for money outflows of 1unit every period for 9 periods, a zero flow for the tenth period and money inflows of 1 unit for every period from 11 to about period 35, results in the curve in figure 1.

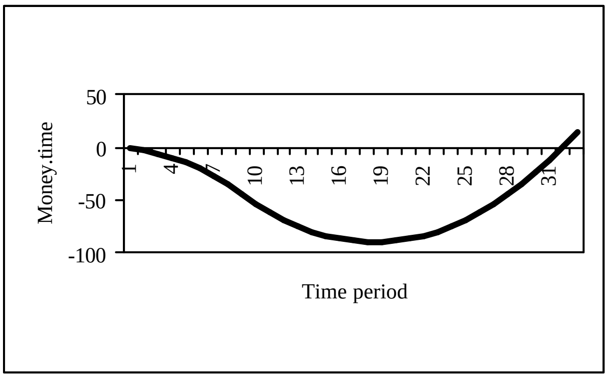


Fig. 1. Demonstrating the flush point

The point where the flush value is equal to zero is known as the flush point. It can be interpreted as the time period in which the system has fully recovered from not having the money available for other uses. In this example the flush point is about 32 time periods.

The flush point cannot be determined with precision. The input data at any project stage are only estimates of future money flows.

The earlier the flush point, the more value can be realised. Management actions such as delaying the outflows, reducing the lead time of the project, reducing the amount of the outflows, increasing the amount of the inflows, getting inflows earlier will all result in an earlier flush point and therefore more value.

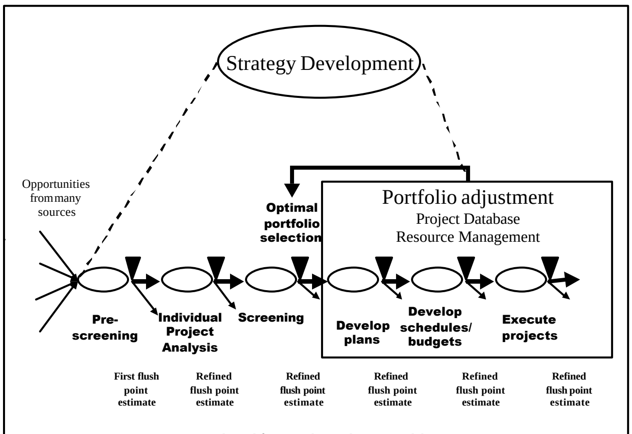
To leverage more value it is therefore necessary to do more valuable projects faster.

3. THE VALUE ACQUISITION PROCESS

An organisation needs to ensure that the projects on which it is using its limited resources will deliver early flush points if it wants to maximise value. A process needs to be employed that can select projects from the set of available opportunities in such a way that the expected value will be maximised. For this process to be effective, the following propositions from Archer and Ghasemzadeh [5] need to be considered:

1. Strategic decisions concerning portfolio focus and overall budget considerations should be made in a broader context that takes into account both external and internal business factors, before the project portfolio is selected
2. The project selection framework should be flexible enough so that in analysing relevant data and making choices of the type of projects at hand stakeholders can choose in advance the particular techniques or methodologies with which they are comfortable.
3. To simplify the portfolio selection process, it should be broken down into a number of stages, allowing decision makers to move logically towards an integrated consideration of projects likely to be selected, based on sound theoretical models.
4. Users should not be overloaded with unneeded data, but should be able to access relevant data when it is needed.
5. Common measures should be chosen which can be calculated separately for each project under consideration. These will allow an equitable comparison of projects during the project selection process.
6. Current projects that have reached major milestones should be re-evaluated at the same time as new projects being considered for selection. This allows a combined portfolio to be generated within available resource constraints at regular intervals due to (a) project completion or abandonment, (b) new project proposals, (c) changes in strategic focus, (d) revisions to available resources and (e) changes in the environment.
7. Screening should be used, based on carefully selected criteria, to eliminate projects from consideration before the portfolio selection process is undertaken.
8. Project interactions through direct dependencies or resource competition must be considered in portfolio selection.
9. Portfolio selection should take into account the time dependent nature of project resource consumption
10. Decision makers should be provided with interactive mechanisms for controlling and overriding portfolio selections generated by any algorithms or models and they should also receive feedback on the consequences of such changes.
11. Project portfolio selection should be adaptable to group decision support environments.

The proposed process can be depicted diagrammatically as follows in figure 2:



(Adapted from Archer and Gasemzadeh, 1999)

Fig. 2. Value acquisition process

The flush point as value metric can be used throughout this process as a common metric (proposition 5). In the assessment of an opportunity, a rough estimate of money flows can be made with a coarse time interval as an assessment criterion. In subsequent steps the flush point can be refined as better information becomes available.

The major determinant of process speed of many discrete processes is provided by the delays experienced by the flow entity. (Schonberger and Knod [6]) In a typical value acquisition process, delays are mostly the result of infrequent review events. The unavailability of resources to make the decision or to develop the necessary information can cause delays as well.

Decision makers have to make decisions despite a degree of uncertainty. Full certainty is realised only when history is reviewed (perhaps not even then). It is therefore necessary that uncertainty be reduced at each step in the process to enable the next decision to be made. This should be the driver for the activities. The flow would be hugely delayed if a decision could not be made at an infrequent review because uncertainty has not been sufficiently reduced. This would cause a project entity to consume resources continually and unnecessarily. If the frequency of the reviews was increased (say from once a quarter to once a month), then the lead-time of the process could be a third of the previous lead-time and the negative effect could be reduced.

The use of a value metric such as the flush point could provide the discipline to continually reduce uncertainty of information, thus facilitating the making of decisions. A new estimated flush point could be required as essential information at each review.

A word of caution though. Any metric that is based on estimates can be manipulated to suit other agendas. The assumptions that estimates are based on need to be considered carefully as part of the review process.

In an organisation with limited resources, one of the most crucial assumptions that has to be made is their availability at a point in time in the future. This is essential input data for decisions to leverage resource usage for increased value.

The schedule of resources is thus one of the crucial data sets that will reduce uncertainty for decision makers. Many activities of the value acquisition process need to be included in these schedules as many key resources are involved here as well as in projects.

4. THE VALUE DELIVERY PROCESS

Projects on the value stream are planned and scheduled and the value delivery process begins. This process is typically the major consumer of limited resources.

Two scheduling issues need to be considered to leverage maximum value with limited resources. Each project needs to be completed with the shortest lead-time, given the resources available (as well as their loading through involvement in essential processes) and the highest number of valuable projects need to be completed, given the limited resources. The Critical Chain approach, as developed by Goldratt [7], is discussed below to address these issues.

4.1 Reducing the lead-time of projects

4.1.1 The problem

The lead-time of projects is determined by adding the durations of the tasks on the longest set of dependent tasks. This is traditionally known as the critical path. The critical path approach assumes that the resources to perform the activities are all available. The dependencies between activities are assumed to be technical dependencies although it may be as a result of resource limitations (activities requiring the same resource are modelled as dependent).

Activity duration estimates are almost always done under conditions of uncertainty. Uncertainties can be classified as task uncertainty (little knowledge on what the content of the task is) or environmental uncertainties (I do not know when I will be able to work on the task, given my working environment). In the environment under consideration, scarce expensive resources experience high environmental uncertainty, while their task uncertainty is relatively low.

Resources are typically measured by how well they achieve due dates. Any activity duration estimate made under these circumstances has to include a significant amount of safety time.

The quantum of the safety is unknown. The resource does not quantify it at all and often denies that he is protecting himself.

Assuming that the distribution of activity duration is skewed to the right (log normal) and that estimates are done to assure a high level of confidence that the end date can be achieved gives an amount of safety included in the estimate of 100% or more.
Under these circumstances the lead-time of a project is of such a length that the probability of completion on time seems to be very high. Project due dates are, however, often not achieved.

The main reason seems to be that the task due dates are missed even though protection has been factored in at the activity level. Resources delay the start of the activity for as long as possible (the student syndrome), disincentives exist that prevent resources from reporting early finishes and the work expands to fill the time.

4.1.2 The solution

The longest set of dependent activities is defined taking into account technical and resource dependencies *a priori*. This results in the definition of the critical chain of the project. When no resource dependencies exist on the project, the critical chain will be the same as the critical path (a rare event in the environment under consideration).

It is recognised that the project needs to be protected against uncertainties. As protection already exists in the form of protection at activity level, an opportunity is available to achieve the required protection with shortened lead times. Given the assumptions stated above, activity durations are cut in half as a first approximation. An activity where this obviously cannot realistically be done is excluded. The safety thus removed from the activities is placed back onto the project in the form of protection time buffers. Aggregation theory and the Central Limit Theorem (Moder and Phillips [8]) allow for reducing the protection further. Only half of the safety removed is replaced as buffers. Buffers sizing will be discussed in more detail in the next section.

The time buffers are placed on the project schedule in such a way that the project due date is protected from variation in the durations of the activities on the critical chain (project buffer) as well as being protected from variation in durations of the activities feeding into the critical chain (feeding buffer).

The result is shorter project lead-times that still have a high probability of being realised.

Critical chain schedules estimate the appropriate starting times of activities in a way that provides protection for the project without having to start activities as soon as possible. This makes it possible for management to ensure that subsequent activities are started on the completion of preceding activities to gain time on projects.

As a consequence the workload on resources is estimated in an aggressive way. Some form of buffering need to be included on resource schedules for their protection. This provides the opportunity also for resources to spend time on the completion of one activity before starting another, reducing the need to multi-task.

The visible project and feeding buffers are used as management tools to determine project status and as an objective priority system for resources and project managers. This management process is referred to as buffer management and is discussed in more detail later.

Updating of projects during execution is done in such a way that remaining duration of the rest of the project is estimated and updated regularly with the latest information. Uncertainty is continually reduced in this way, which results in increasing the validity of schedules. An effective Project Management Information System is, of course, a necessary condition to make this information accessible (propositions 4 and 10 [5]).

The aggressive task duration estimates that resources are working to can be used to change behaviours that cause time losses.

Many key resources in an organisation are required to work on more than one project as well as essential processes (maintenance or value acquisition), as has been seen. If their non-project work requires ad hoc availability to deal with breakdowns or unexpected highly promising opportunities, then the buffers might be expected to be sufficient to absorb their temporary unavailability for project work. If, however, their involvement is required in a planned process of frequent exploration and opportunity development, then their scheduled workload should be included in the scheduling of multiple projects discussed next.

4.2 Increasing the number of valuable projects delivered with limited resources

4.2.1 The problem

Too much work is released to resources when the rate of project acquisition is higher than the rate of delivery, resulting in work queues. The number of resources is reduced to the lowest possible levels (right sizing) when the rate of work acquisition is less than the rate of delivery, resulting again in work queuing in front of resources. The flow of work is delayed and resources are forced to multi-task in order to satisfy widely different priorities of project managers, resource managers and top management. Multi-tasking increases the elapsed time of activity completion by an order of magnitude.

The workload per resource is based on the estimates of activity durations on projects. These estimates typically include a large indeterminate amount of safety to accommodate the required multi-tasking, as has been shown.

4.2.2 The solution

Goldratt [2] developed an approach to production planning, scheduling and control known as Drum, Buffer, Rope. This approach identifies the capacity constrained resource in a production process (the Drum), determines the time buffer that work needs to be released into the system earlier than required by the constraint (Buffer) to ensure its full utilisation and releases only that material which is required by the drum schedule into the system (Rope).

The same approach can be applied to the multi-projects environment that has to complete a number of projects (jobs/orders) with the same set of resources.

A drum resource is selected. The data that determines workload on resources is imprecise and cannot be used in a deterministic manner to calculate workload. The best that can be hoped for is to identify a few of the most heavily loaded resources, from which one is selected. Selection criteria such as cost of the resource and the scarcity of the skill can be included in this selection process.

The workload (from aggressive activity durations of project as well as essential process work) of the drum resource is scheduled for its finite capacity. This results in the placement of work on a timeline with no time gaps between different activities. This is obviously not feasible and a capacity buffer (100% of safety removed is typically used) is inserted between scheduled work on different projects. The drum resource's work on different projects is thus effectively staggered on its schedule. The scheduled process work can be scheduled within the capacity buffers. The whole project is staggered when the other project activities are clustered around the work of the drum resource on a project.

The work on the value acquisition process could be planned and scheduled as if it is another project (if necessary).

This synchronisation of work could include project priorities determined by the project value as well as externally imposed due dates.

The synchronisation has the effect that the work of other resources is also staggered. This reduces the need for multi-tasking overall, thus reducing delays on projects.

This approach calls for project work to be released to resources only according to the drum schedule. Work is delayed in order to finish projects earlier. Work-in-progress is reduced, thus making it easier for resources to make good prioritisation decisions when required to multi-task. The buffer status of the projects provides additional clear priority signals.

5. BUFFERS AND BUFFER MANAGEMENT

Buffer management is based on statistical process control (SPC) principles, as developed by Walter Shewhart [9]. These principles distinguish between special and common causes of variation. A system is under control and therefore predictable if only common causes of variation are present.

Buffers are used in the value delivery process as time buffers to ensure that individual projects, as well as the organisation, are protected against uncertainty. The buffers are sized to be effective protection against common cause variation (Leach [10]). Buffers sized to protect against special causes variation, such as a natural disaster, will be unacceptably long. The simple approach previously described is sufficient as first approximation of buffer size (conservative), given that the activity duration estimates are imprecise data. Buffer sizing can be refined through the application of the Central Limit Theorem [10].

Buffers are divided into three zones. The first third of the buffer is the green zone. When buffer consumption has penetrated into the green zone, the system is deemed still to be under control and no action is required. The second third of the buffer is the amber zone. Penetration into this second zone indicates that the system might be unstable. Management action is to increase vigilance and to plan for action in the event that the system proves to be unstable. When the buffer consumption is in the last (red) zone, the system is clearly unstable and the project is at risk. Action has to be taken immediately and sustained until the buffer has been recovered back to the green zone and a stable system that is under control and predictable is again established.

6. INCREASING VALUE THROUGH LEVERAGING LIMITED RESOURCES

The performance of any system is determined by the performance of its constraint(s) [2]. A constraint can be a physical limitation, such as a resource with the least capacity, or it can be non-physical and is then reflected in the policies of the organisation.

It was shown in sections 1, 3 and 4 that two primary value chains are present in organisations that generate money through the delivery of multiple projects using limited resource. These chains are described as the value acquisition process and the value delivery process. A holistic approach to this system is required to ensure that value is continually increased through leveraging the limited resources.

The physical constraint of this system is the limited resources. But this constraint is typically not exploited because of a number of policies. These policies comprise scheduling resources to multi-task, cutting costs everywhere in order to improve profitability, measuring the performance of a project in terms of project profitability, strict time control systems to ensure high resource utilisation, and many others.

The key to the Theory of Constraint approach to managing this system is the knowledge of organisational capability in the future with a sufficient degree of confidence. This is achieved through the active management of a small number of buffers that protect key steps in the integrated system.

Buffers in the value delivery value chain have been described in some detail. The same approach can be applied to the value acquisition process to achieve synchronisation between the value acquisition rate and value delivery rate.

The capability of the organisation can be defined as the value generated per unit of constraint (drum) time [2]. This approximates the value delivery rate. A necessary condition to increase the value delivery rate is to ensure that the drum resource has work of high value to do at all times. This can be ensured through the management of a value buffer from which the drum resource draws work. This buffer should rather be viewed as a bucket that is managed as a buffer. The outflow from this buffer for the scheduling horizon is known with a high degree of confidence. The leak (waste stream) in the bucket can be estimated from past experience. The bucket (buffer size) can be determined through estimating an inflow rate and applying a protection constant.

This buffer is essentially also a time buffer. It is the amount of time that an order (project) will wait before it is worked on by the drum resource. It is equal to the length of the planning horizon, which is largely determined by customer tolerance time.

The Theory of Constraints approach recognises the variability and dependencies in the whole of the system. An organisation can leverage limited resources for more value through the design and management of an integrated value acquisition and delivery process. The proposed management system synchronises the delivery of projects and the value acquisition rate around the schedule of a drum resource.

Variation in the system is managed through the placement and active management of time buffers in the dependent primary processes of value acquisition and value delivery.

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