

# **The Physics of the Value Chain**

## **Towards a Dynamic Theory of Strategy**

By

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M.S. Computer Science  
Tufts University, 2003

SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF

MASTER OF BUSINESS ADMINISTRATION  
AT THE  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

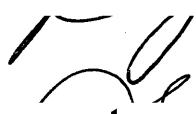
JUNE 2017

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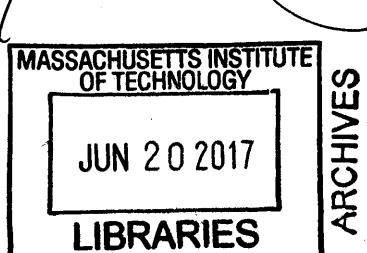
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Submitted to MIT Sloan School of Management  
on May 12, 2017 in Partial Fulfillment of the  
requirements for the Degree of Master of Business Administration.

### **Abstract**

Understanding the evolution of a firm's competitive advantage in a changing environment over time remains one of the most important topics in competitive strategy. We build on a recent stream of research in the arena of the dynamic resource-based view to propose a simple heuristic for strategic corporate foresight powered by Little's Law. Notably, we propose a throughput equality required to align and synchronize resources in the value chain. We borrow the terminology of the supply/demand chain and assembly process representation to propose a fundamental construct for manifold decomposition of the value chain. Our proposed heuristic simplifies the dynamic complexity of the value chain.

**Thesis Supervisor:** Duncan Simester  
**Title:** NTU Professor of Marketing

## Acknowledgments

I have likened my experience in the MIT Sloan Fellows Program to the experience of “the best book” I have read so far, and (as with any good book) I wanted to turn the pages ever so slowly. I am grateful to my brothers and sisters in the Sloan Fellows 2017 family for inspiring me. I would like to thank Stephen Sacca for his friendship, Cathryn Noyes for her kind support and everyone in the Program Office for making the most enriching year for me and my family.

I have benefited greatly from the academic thought leadership and kind advice of many faculty and students at Sloan.

From the day of the first lecture, my advisor, Professor Duncan Simester, has elevated my thinking and helped me conceptualize key issues in strategy and marketing, and inspired the core questions underlying this thesis. Throughout the year he has guided me patiently as I levitated in the universe of thought while making incisive recommendations to foster my efforts in the most kind and thoughtful manner.

The thinking in this paper benefited greatly from the coursework and discussions with distinguished faculty. I would like to thank Professors Robert Freund, John Sterman, Robert Gibbons, Erik Brynjolfsson, John Little, Vivek Farias and others on whose course material I have relied heavily in my work. I would like to thank Artem Timoshenko for his friendship and encouragement as he found time to support me while working on his own Ph.D.

I would also like to thank Betsy Fox at MIT's Writing and Communications Center, who has patiently helped me with the language and disciplined my grammar.

I gratefully acknowledge financial support from the Luys Scholarship Program administered by the Luys Foundation.

I would not have had the luxury of “thinking” if not for the love and support of my friend, Ara Barsam, and my family. Thank you!

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## Chapter 1 – Introduction

The notions of causality and duration have been implicit in the language of the strategic thought leadership - as in *creating, capturing and delivering* value (Simester 2016); *sustainable* competitive advantage (Porter 1991); or *dynamic* capabilities (Teece et al. 1997). The duo of spatial causality and duration that underpins the reality of the physical space is matched by the sequencing and time-dependency in the arena of strategy theory that has been examined largely through a static lens. Ghemawat & Cassiman (2007) observe that, “for a long time (longer than strategy has been formally studied as a field in business) center stage has been occupied by the interactions among a firm’s choices *at a point in time.*” The importance of the inquiry has been amplified by a number of scholars.

Dr. Edith Penrose (1959) who recognized early the importance of resource accumulation in the firm’s performance, defined later as the resource-based view of strategy (Wernerfelt 1984), offered the following lucid, seemingly simple words on sequencing and time-dependency:

There are important administrative restraints on the speed of the firm's growth. Human resources required for the management of change are tied to the individual firm and so are internally scarce. *Expansion requires the recruitment of more such resources. New recruits cannot become fully effective overnight. The growth process is, therefore, dynamically constrained* [emphasis added].

Porter (1991) termed the problem a longitudinal one and contrasted it with a cross-sectional approach that seeks to establish stationary criteria for the firm's performance. He distilled the difference between these concepts when he wrote, "the cross-sectional frameworks address the choice of strategy given whatever the array of capabilities is at a given point in time." Porter points to the crucial nature of this distinction for the goal of strategy by stating, "The task of strategy is to maintain a dynamic balance and not a static one."

Dierikx & Cool (1989) provided a critical insight to the field of strategy when they conceived of the asset accumulation problem as one of the stocks and flows. They wrote, "... the strategic asset is the cumulative result of adhering to a set of consistent policies over a period of time. Put differently, strategic asset stocks are accumulated by choosing appropriate time paths of flows over a period of time." They then intuit that "imitability of an asset stock is related to the characteristics of the process by which it may be accumulated." Their quote below wittily encapsulates the time compression diseconomies of asset accumulation:

... sustaining competitive advantage is perhaps best illustrated by the following dialogue between a British Lord and his American visitor: "How come you got such a gorgeous lawn?" "Well, the quality of the soil is, I dare say, of the utmost importance." "No problem." "Furthermore, one does need the finest quality seed and fertilizers". "Big deal". "Of course, daily watering and weekly mowing are jolly important". "No sweat, just leave it to me!". "That's it." "No kidding?!" "Oh, absolutely. There is nothing to it, old boy; just keep it up for five centuries."

The focus here is clearly the factor of time-dependency.

Helfat & Peteraf (2009) refer to the problem of dynamic capabilities, “as one of the most central and difficult questions within the strategy domain, this might well be characterized as the Holy Grail of strategic management.” Their point reinforces the complexity and significance of the dynamic dimension. They emphasize the key question of not only “what” but “how” adding that “the literature on resource acquisition and development has been concerned primarily with “what” questions. There has been less attention paid to “how” questions and to process issues ... and our current understanding of resource acquisition is deficient along those dimensions.” They suggest that the answer to the question of “how” could be addressed through adopting the process view of the resource accumulation: “our understanding of the creation of heterogeneous resource positions can benefit from research that takes a process perspective ... to refer to both research that focuses on managerial and organizational processes and studies that *examine how something unfolds or evolves over time* [emphasis added].” Building on their inquiry into the resource acquisition process, in this paper we focus on answering a *prior*, a more fundamental question of “when” that combined with “what” (set of resources) would underlie the “physics” of “how.”

By adding *time* to the discussion about strategy, we are adding a new dimension that could significantly complicate the value system model and increase the cognitive difficulty of understanding the dynamic implications. Porter (1994), as cited in Sheehan & Foss (2007), suggests that the tools of Operations Management (OR) with its focus on complex optimization

might be best suited to address the longitudinal problem. More recent work in integrating the system dynamics and strategy theories, RBV in particular, have sought to bring the two fields toward a common view and vocabulary (Warren 2002), (Morecroft 2008) and (Gary et al. 2008). Morecroft asks, “What better way to understand firms and firm performance than with a ‘theory of structure’ capturing causal relationships and decision making processes that drive the dynamic behavior of firms and industries over time?” Building on model-supported strategy work, he argues that “a combination of system dynamics and contemporary ideas from the strategy field ... can yield compelling and credible theories.” Morecroft states that the model is “constructed entirely from concepts fundamental to system dynamics analysis” and he asks whether the field of strategy enhances this discussion, “why is it helpful to re-interpret this rich model-based theory with concepts from the mainstream strategy literature?” This is an important question that deserves attention. Let’s consider an earlier definition by Porter (1991) who wrote that “the strategy, in modern language, is a solution to the agency problem that arises because the senior management cannot participate in or monitor all decisions.” The tools of System Dynamics along with advances in computational and data science provide fertile opportunities for the development of decision support systems that could aid strategy formulation. However, all of these tools support the strategic thought process and cannot, should not replace the “the lost art of thinking in the large organizations” (Simester 2016).

A key object of this paper is to propose a simple heuristic as an intermediary between the conceptual thought tools of RBV, the quantitative methods of Operations Research and the management flight simulators of System Dynamics. The ambition is to improve the interpretability

of the value chain model in the dynamic context, while enabling the type of thought experiments that allow the managers to understand the scope of the strategic inquiry and ask the right questions that precede any detailed modeling effort.

The Literature Review in Chapter 2 reflects our ambition to seek horizontal connections between several disciplines encompassing strategy, system dynamics and operations research. Chapter 3 defines the key terminology and principles and uses them to construct our proposed heuristic. Chapter 4 applies the heuristic to the example of an airline as a complement to Morecroft's canonical use of People Express study (Morecroft 2008). We also apply an example from Cool et al. (2015) to depict the competitive dynamics in the resource-time space. Chapter 5 concludes the paper with a summary discussion.

## Chapter 2 – Literature Review

The importance of time and the resulting dynamic complexity of the strategy field was recognized by a number of scholars. Identified early by Penrose (1959), it was defined later as a longitudinal problem by Porter (1991), who contrasted it with the cross-sectional view that is concerned with the firm's array of capabilities at a given point in time. Highlighting the importance of the inquiry, Ghemawat & Cassiman (2007) observed that much of the focus of the strategy field has been on this stationary view while the dynamic implications have been largely unaddressed. Porter (1991) identified three "promising" research streams, including the resource-based view of the

strategy by Wernerfelt (1984), to address the longitudinal problem. Dierikx & Cool (1989) conceived of the resources as asset stocks that accumulate or deplete over time. Relying on their concept of asset stock accumulation, a group of scholars including Morecroft (2008), Warren (2002), and Gary et al. (2008) have linked the dynamic RBV to the core concepts of the System Dynamics - the stocks and flows – in order to bring the full rigor of the “theory of structure” to the task of illuminating the dynamic implications in strategy. Sterman (2010) and Cronin et al. (2009) studied extensively the robust cognitive limitations for understanding asset accumulation, which, in part, underlies our ambition to improve the interpretability of the value chain model in the dynamic context by exploring the potential of a higher-level heuristic. Repenning & Sterman (2001) developed the theory of the “Capability Trap” to explain the failures of many process improvement programs. They posit that the “improvement paradox” is a systemic problem – a failure that is brought about by the interaction of organizational elements in the system – labor, equipment, workers, managers. We propose extending this model to the concept of dynamic capabilities in strategy to investigate the adaptive capacity of the firm – its ability to adjust the resource stocks in response to changes in its environment - through the lens of the Capability Trap.

The demand-supply chain model (DSCM) was conceptualized to address the value reengineering in the traditional supply chain (Holmström et al. 1999). Auramo et al. (2004) applied the model to identify missing supplier capabilities and Matthias et al. (2005) used it to demonstrate collaboration and alignment in the consumer goods supply chain. Later, it has been extended to support economic organizing in industrial services (Holmström et al. 2010). DSCM was endorsed as a new business model that integrates the marketing and supply chain (Jüttner 2007). Haddad

et al. (2013) proposed a measurement taxonomy for supply chain and marketing integration. Viewed through an inventory optimization lens, the integration between marketing and operations can improve demand management in order to have efficient levels and avoid excess inventory (Hadadan 2016). We rely on DSCM concepts including the integration of operations and marketing to build the assembly view representation for the value chain.

Drèze (2009) discussed the customer equity and the customer life-time value vis-a-vis the customer flow as a result of acquisition and retention processes. Ceprini & Little (2014) applied generalized Little's Law to the flow of assets in a financial portfolio. Cappelli (2009), for example, considered supply chain implications for internal talent development systems, and Shah (2017) suggested the application of supply chain thinking by viewing recruitment as an inventory problem. Allen et al. (2013) focus more broadly on the entire human capital supply chain and illustrate the applicability of value stream mapping to talent acquisition. Angelus & Porteus (2008) formulate a "fixed-asset assembly problem" where the asset is the production capacity. Their contribution is relevant to our discussion of environments where, "the components remain unassembled into a physical unit, such as when the components are people undergoing training in different skills and each unit of operating service system capacity requires a fixed number of people of each skill to be available." Our objective is not to offer an exhaustive demonstration of different flow and asset views but rather to highlight that key resource categories and business areas have been modeled in a meaningful way in this manner.

## Chapter 3 – Key Concepts

### Little's Law

Little's Law (LL) is a theorem in queuing theory that has numerous applications in various fields, notably in operations management and computer architectures. The uses of LL are far-reaching in practice from applications in OM such as staffing emergency departments in hospitals to marketing science. LL has become well known because of its theoretical and practical importance (Little 2011)..

LL is a simple three variable formula that states the relationship between the average time an item spends or resides in the system, the average number of elements in the system at given time and the average throughput, the rate at which the elements move across the boundaries of the system.

$$L = \lambda * w$$

Where L is the average number of items in the system, the lambda is the throughput and the w is the average residence time. The power of this simple formula is in that knowing two of the variables we could easily derive the third and what is remarkable is that that formula is very robust and holds under very general conditions. The Generalized Little's Law (GLL) is an important enhancement to the formula that allows assigning custom weights to the items in the system, which could be used in a variety of applications (Little 2011).

## Resource - Time

If we took snapshots of the value system at equal time intervals, we would produce a stationary view of fixed resource levels as measured at a given point in time. If the relationships between the stocks are known, this picture would be informative and indeed represent the cross-sectional view discussed earlier in this paper. Such a *resource map* would provide the lineage of each resource through the value chain and fully describe the firm's strategic asset accumulations at a given time. And since resource stocks define the competitive position and flows define changes to the competitive position, the time series of such snapshots would allow the plotting of changes to the position of the firm in the market. Assuming a single resource, we could depict each snapshot value as a point in a two dimensional resource-time space (Figure 1). When we add an additional dimension of time to a set of N resources, we have a new N+1 dimensional space which could be termed *resource-time*. There would be a limit to the rate of the value chain adjustment, constrained by the maximum processing rate of its "weakest" link – the resource stock that is the slowest to adjust. As such, the maximum rate of the growth of the firm is constrained by the expected accumulation rate of its most sluggish resource. The inclines of the lines forming the two cones, as shown in Figure 1, correspond to the accumulation rate for the same resource for firms A and B measured at stock levels 1 and 2 at time = 0. For simplicity, we assume that the maximum accumulation and depletion rates are the same. As a result, the space constrained by the cone in Figure 1 represents the universe of potential paths a firm could realize in the resource-time space as estimated at time = 0. While the shape of the cone may change with time, we propose that there could be a reliable estimation horizon that would limit the likelihood of the firm to *break out* of its cone. Furthermore, we propose that the *shortest path* between two positions in the

resource-time space corresponds to the straight line, i.e., a constant rate of resource adjustment. Intuitively, we could interpret this straight line as the firm's ability to set a correct *direction*, the rate of growth, once at the outset and maintain it over the time period required to attain the resource position. We would demonstrate its application in Chapter 5 using an additional time delay constraint imposed in the R&D example by Cool et al. (2015).

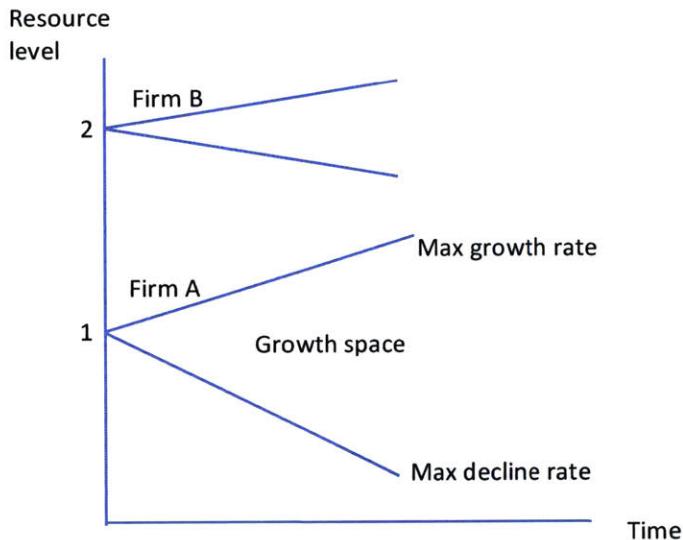


Figure 1.

## Assembly View

While it could be argued that the distinction between the supply and the demand views afforded by the DSCM representation is merely a matter of perspective, we contend that their integration defines a materially meaningful position in a value chain that may be termed – the *value transfer node*. This node is important because an actor in this position is primarily concerned with

coordinating *its* supply with *its* demand. The key rationale underlying the assembly view is that the value delivered at a particular stage in the value chain, the value transfer node, either through cost savings or differentiation, is the aggregate product of the actions by the upstream actors. Analogously, the demand is the cumulative result of the order decisions that propagate through all downstream actors relative to the value transfer node. Simply put, the customer of my customer sees me as the supplier of its supplier. So it is indeed a matter of perspective but a crucial one since the decisions within the boundaries of the firms for addressing the questions of “what” to order/supply and “when” are independent for each firm in the value chain. Hence, the principal benefit of the assembly view relative to a particular link of the value chain is to distill the focal point that separates where the value is created and delivered from where it is recognized and demanded (Figure 2).

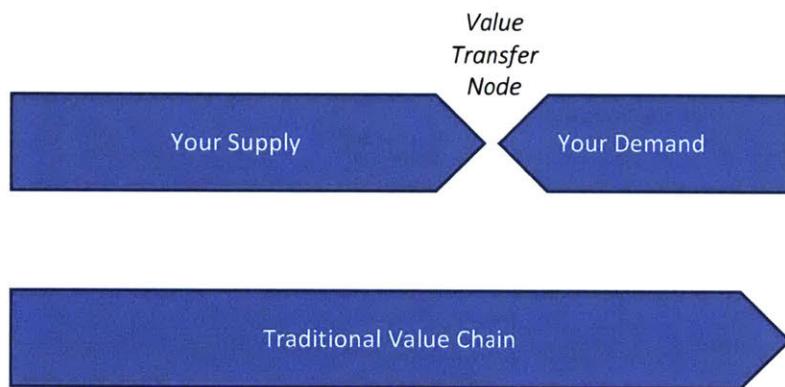


Figure 2.

To better illustrate the concept of the value transfer node, we build on key concepts of RBV to enhance the following definitions of strategy by Porter (1991) and resource complementarity by

Warren (2002). We do so by introducing the concept of resource synchronization. Porter (1991) writes, “Strategy is the act of aligning of company and its environment.” In defining resource complementarity, Warren (2002) asks of resources, “do they work well together?” We detail Porter’s and Warren’s definitions in the next paragraph.

We interpret Porter’s definition as implying that the firm’s *strategic visibility* into the environment – that is the knowledge of resources, causal structure, and flow rates external to the organization - informs the firm’s strategic task of *aligned deployment* of its internal resources and capabilities.

We read Warren’s definition of complementarity as a passive resource characteristic, i.e., one of *compatibility*. We prefer to ask whether the resources could be aligned to work well together.

Here by “alignment” we mean both the matching of resources – the optimal combination of resources as in a stationary problem - and the synchronization of resources - the timing of the resource availability. A pair of socks could be matched - we could coordinate stationary attributes such as color or pattern - and could be sold or worn together - a synchronization problem.

Extending the metaphor, we propose that the matching problem asks the question of “what” and corresponds to the cross-sectional problem posited by Porter. The synchronization, on the other hand, considers the question of “when” in addressing the longitudinal problem. In the value chain context, alignment answers the question of “what value” is created vs “what value” is recognized.

Synchronization answers the question “when the value” is delivered vs “when the value” is demanded. A piece of *expensive equipment* requires to be matched with *skilled labor*. The *availability of the equipment* would have to be scheduled with the *availability of the operator*. A team of scientists would require *certain amount* of R&D funding *in a given period of time*. The task

of strategy, therefore, is formulating the set of *alignment* policies that best combine the firm's resources - *both in substance and in time* – while anticipating changes in its environment.

Within the organization, the choice of what side to call demand vs supply is arbitrary and could be informed by the emphasis on the semantics of internal client vs provider. The modeling is agnostic to this choice. The key concept is that the supply chain mantra - the right product at the right place and the right time - is equally and simultaneously applied to the demand chain – the right customer, at the right place, at the right time. In this context, matching customer preferences to product attributes would be considered a supply side task (product design, fulfillment), part of the firm's persuasive optimization in targeting a particular customer segment. The delivery of these matched preferences at the time when they are (most) recognized and demanded would correspond to the task of synchronization. In other words, the dynamics of the demand flow is relative to the dynamics of the supply flow in terms of both perceived value and time.

We propose to model the supply and demand as converging resource flows that are combined in a single stage assembly process at the *value transfer node*. For example, as shown in Figure 3, customer equity generated as part of the marketing operation would represent a demand flow, and the finished goods produced by the upstream operations would comprise a supply flow. The assembly of these two components would realize a sale. This perspective, for example, would allow us to recast the stochasticity of resource demand or supply, the unpredictable lead time variability, as a material availability problem while the matching of the flows would seek to address the variability in the resources – whether the supply meets the specifications of the demand. The

former corresponds to the synchronization constraint in the manufacturing assembly process.

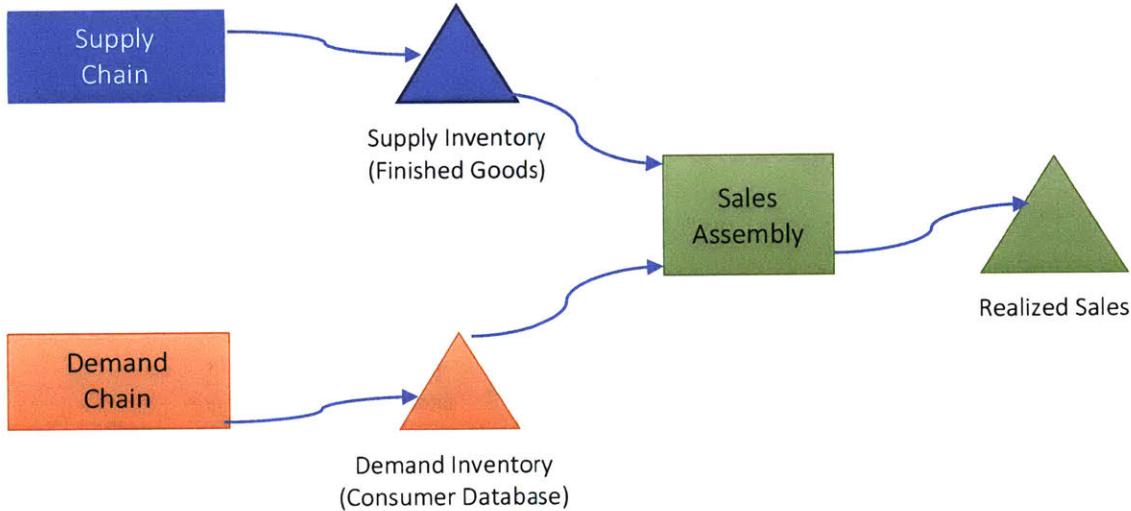


Figure 3.

This assembly view brings out the duality and relative nature of value creation in the value chain. For a given resource stock, it allows us to build a manifold of the value chain topology based on the resource visibility. Once a resource is identified, a key question to ask is, “who is waiting for it?” The customers are waiting for a product or service, the warehouse staff depends on logistics and manufacturing, the HR waits for the recruiters, and so on and so forth.

The cross-sectional view postulates that the value is created through cost savings or by differentiation. In the longitudinal context, the value created by the supply and the value perceived by the demand side are both functions of time. The timing of the value delivery is relative to the timing of the demand expectation. As such, the value delivered is relative to the value perceived, both in amount and time.

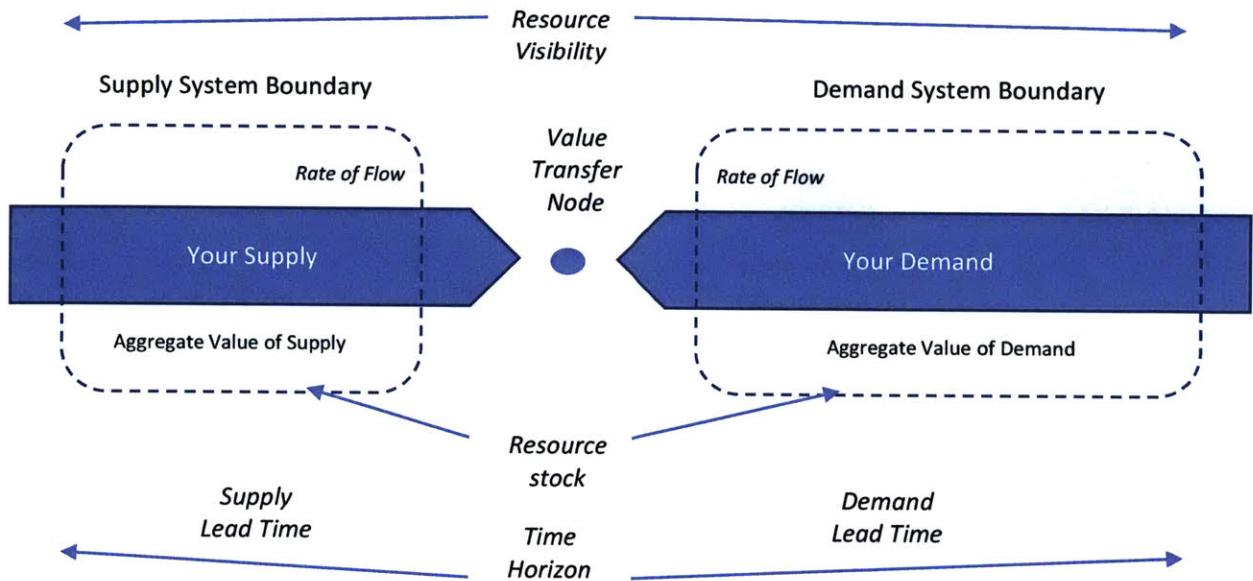


Figure 4.

We extend the bathtub metaphor of Dierikx & Cool (1989) to model a segment of the value chain as a resource stock in process with the help of the assembly view featuring a supply side and a demand side. We propose to draw the boundary of each system, supply and demand, to include the resource stock in question (Figure 4). The inflow to this stock would be defined by the exogenous accumulation rate of the input by the upstream system and the outflow (which would be equal to the inflow in a steady state) would represent the depletion rate of the resource. In many contexts the output rate is determined exogenously, i.e., sales output is the “reason d’être”, hence we would use that instead of the inflow rate (Little 2011). Alternatively, the manager sets the inflow rate to the resource of interest in order to align and synchronize with the demand.

Each stock could serve an internal or external demand or both. Examples could include a demand stock comprised of B2B orders or customer equity in a B2C setting. Application of LL allows the system boundary, where the resource flow enters the system, to be highly abstract. The system could be very general as well. For example, in a hospital setting, it could include the treatment facility and the waiting room or it might be only the waiting room. In other words, the system could be applied to both stocks and resources in *process* or ones that are *waiting*. One of Professor Little's insights is that the resource in line is also "waiting" as in undergoing "processing" or "being maintained". Viewed from this perspective, it does not matter whether the system is segmented into stocks (i.e., waiting queues) or processing units. As such, LL could be applied selectively to different parts of the value chain. Furthermore, LL could be applied to separate streams within the flow. For example, we could track separately different types of patients as long as we have the two of the LL parameters measured for that segment.

*Proposition 1.* According to GLL for a steady value chain:

$$\text{Supply}/\text{Supply Lead Time} = \text{Demand}/\text{Demand Lead Time} = \text{Throughput}$$

Analogously,

$$\text{Supply}/\text{Demand} = \text{Supply Lead Time}/\text{Demand Lead Time}$$

Where Supply and Demand are the aggregate values of supply and demand resource stocks within their respective system boundaries.

This application of LL allows us to establish a simple relationship between supply and demand in a steady state value chain when expressed in the same units. Notably, it is easy to see that at each point along the value chain, the ratio of the average supply and demand stock is equal to the ratio of average lead times. Furthermore, when specific conditions are met, this relationship is exact. Finally, depending on the time horizon, the equality in Proposition 1 mandates that the supply and demand are synchronized both in substance as well as time. The stocks represented in the units of value address the matching requirement of “what” while the values of the lead times inform the timing of “when”, the question of synchronization. For example, if the lead time of the supply is equal to one month, then the lead time of the demand (including acceptable wait time) would have to be equal or fairly close in order for them to be synchronized with each other.

The key insight is that the average flow rate in the value chain is the proportionality constant between the resources and time for both supply and demand. As such, using the combination of the assembly node and LL, we could derive a simple linear heuristic to inform the longitudinal problem of resource accumulation. When one of the parameters is not easily measured, knowing two of the parameters such as flow rate and resource stock (up to the system boundary) would enable us to derive the third, the time, thus allowing “back-of-the-envelope” estimates for supply and demand dynamics at a particular node of the value chain. More fundamentally, the heuristics provides a foresight mechanism into the future based on resource visibility in the present. We propose that this conceptual model is applicable to the entirety of the supply life cycle and, conversely, the entirety of the demand chain. To demonstrate its application, we will use a simplified airline example with three stocks - airplanes, staff, and customers - in the next chapter.

As a personal and somewhat philosophical side note, a recent question from my classmate compelled me to ponder the extent of our inquiry into the value chain. How far should the model extend and what would be the “end” of it if there is one? Or perhaps it might be thought of as being circular? For example, do we model nature (and the government) as the supplier of the raw material to the mining company? Conceivably, the physics of it, the average sojourn of coal in the depths of earth, could be conceptualized to inform us when the stock would run out at the current extraction rate. Analogously, the natural growth of population and associated demographic processes would determine in part the long-term flow of customer equity. I suspect that the depth of inquiry and indeed of visibility in the causal chain in either direction would be a matter of a strategic time horizon. This horizon would be informed, in part, by the lead time it would take the resource to traverse the value chain, in this case the natural process that effects the accumulation of the supply material in question or the socio-demographic process that would affect the demand. The relationship between this resource “distance” and the time horizon is indeed the subject of this paper.

## Chapter 4 - Airline Example

Fundamentally the stock of value differentiation underlies the firm’s competitive advantage. The stock level dynamics over time determines whether the advantage could be sustained and hence for the accumulation to serve as a strategic resource. The inertia and time diseconomies are the function of the value chain structure and a source of natural advantage in some settings. Extending

the metaphor of an organism, it may be termed as the value chain *metabolism*, characterized by the rate at which it combines and processes the resources in creating new resources, intermediate as well as end-products and services. Ultimately we need to understand and measure how a change in the strategic resource, the rate of *metabolism*, affects the value delivered to the customer.

We apply our heuristic to the example of an airline as a complement to Morecroft's canonical use of the People Express study (Morecroft 2008) using three key resource stocks – airplanes, service staff, and customers. Using the assembly view, the value chain could be decomposed into two key assembly nodes as shown in Figures 5 and 6.

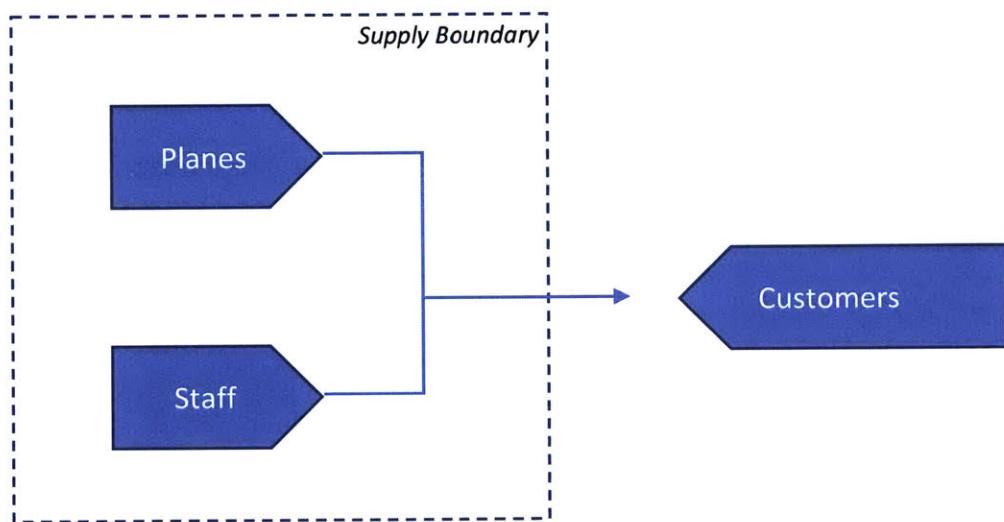


Figure 5.

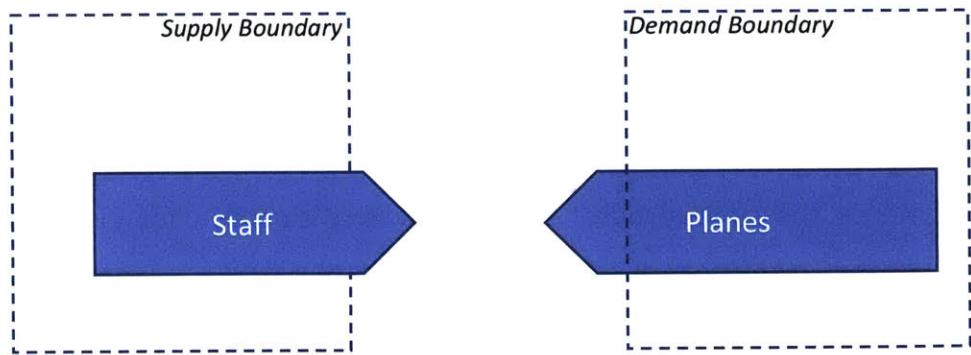
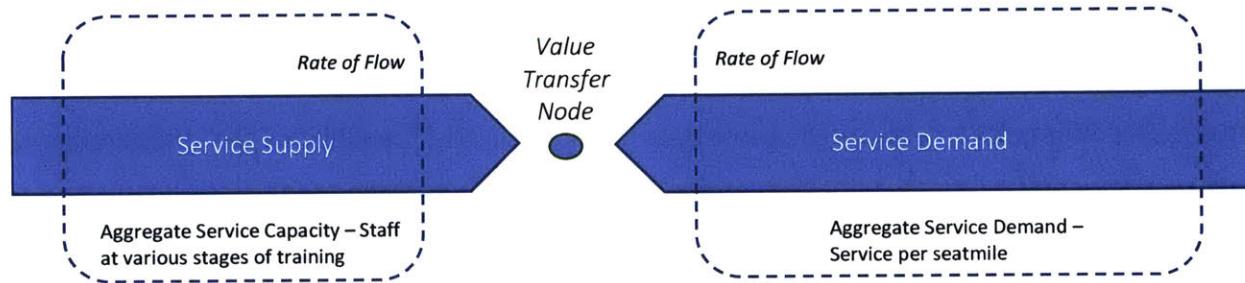


Figure 6.

Figure 7 details the assembly view comprised of staff as the supply flow and airplanes as the demand flow.



*Supply lead time is the induction time required to train the staff; supply is the aggregate service staff capacity at various stages of training; rate of flow is the demand rate for service capacity (staff hours required per unit of time).*

Figure 7.

The assembly node, shown in Figure 5, reflects the alignment requirement of our model - the airline needs to match the supplied *level of service* with the passenger expectations as well as the

*number* of the passengers *when* they fly. The assembly node, depicted in Figure 6, reflects the requirement that the *number of planes* (the number of seatmiles) is matched with the level of service capacity. An increase in the number of planes (seatmiles) increases the service capacity demanded. Hence, the capacity must be available *when* the demand for it is increased.

By decreasing the lead time for service staff induction, the airline is able for the time being to meet the synchronization requirement of the assembly node, i.e., increased rate of service demand, but not the service quality since it takes time to train the staff. While the airline may increase its investment in training, the staff would not be ready overnight. The situation is made worse since the airline has been deeply discounting its prices. The reduction in price (or increase in some other financial benefit) would drive the flow of customers, resulting in an increase in the demand stock (Warren 2002). Hence, both the stock of planes and the stock of customers are in imbalance vis-a-vis the stock of the service staff. If the time it would take the airline to fix this imbalance is more than the customers could tolerate, in other words, if the rate of customer abandonment is higher than the rate of improvement, the airline would find itself in the “Capability Trap” (Repenning & Sterman 2001) and face a potential demise despite seemingly strong resource stock of customers, planes, and staff. Morecroft concludes, “the dynamical puzzle of the rise and fall of People Express becomes transformed into the equally enigmatic puzzle of the apparent overnight switch in the company’s competitive advantage (sustained for five years in a highly competitive industry) to competitive disadvantage” (Morecroft 2008).

Without complex modeling effort, our proposed heuristic would allow us to derive an average estimate of the staff levels required given the training duration to satisfy the growth in planes and customer base. Analogously, the minimum training time required to reach acceptable service capability at a given recruitment rate would determine the capability stock required and the maximum rate at which planes could be added. The key insight offered by the heuristic is that a judicious planning for growth on one side of the node necessitates taking into the account the time-dependency of resource accumulation on the other. Understanding and expecting the lead times at the assembly node, one could plan for the synchronization requirement without sacrificing the quality, the “what” requirement. Achieving a level of differentiation and maintaining it requires understanding the rate at which the differentiation is accumulated (inflow) and the rate at which it is being depleted (outflow). Morecroft suggests that the combination of system dynamics and RBV can explain fragility of competitive position because of the effect the delays and feedbacks and associated nonlinearities can have on stock levels and, particularly, on the hidden intangibles such as reputation and customer service. We add that the first order dynamic effects may become visible by applying the simple heuristic based on LL. If the nonlinear effects remain hidden, at a minimum, our proposed heuristic provides a linear model to highlight the relationship between resource dynamics and time that forces us to consider the issues of resource alignment and synchronization. The time-dependency may hinder the path to growth, but it may also slow down the demise as the time delays work to provide a degree of inertia on the way down. The structure of the value system may be resilient to demise in the same way it might be challenging for entry and growth.

Extending the resource-time metaphor, the difference in the competitive position, which is equivalent to the difference in the corresponding level of the resource stock, is the distance the competitor needs to traverse to catch up. LL helps us establish the relationship between the distance, i.e., resource level, and the rate of change and time. To demonstrate the diseconomies of time compression, Cool et al. (2015) offer the example of two firms competing for the number of new products launched as a result of investment in R&D programs. Firm A starts by investing \$100 million/year and Firm B starts 5 years late but invests \$200 million/year. The authors ask when Firm B would expect to catch up with Firm A. They examine three treatments to highlight the effects of productivity, time-dependency constraint, and cycle time on Firm B's ability to catch up. The time-dependency constraint states that it takes 4 years from the time the investment is made to the time the new product is released.

Without embarking on the simulation provided in the paper, a simple thought experiment could inform us of the dynamics of this rivalry:

$$R = s * t$$

where  $R$  is the stock of new products in \$;  $s$  is the investment in \$/year; and time  $t$  is in years and includes the lead time to develop. Accordingly,

$$500 + 100 * x = 200 * x \Rightarrow x = 5 \Rightarrow \text{it takes } (5 + 4) + 5 = 14 \text{ years to catch up.}$$

This example demonstrates how simple accumulation effects in the presence of a time constraint are not immediately obvious. The assumption that increasing the flow rate twice would result in catching up is a vivid example of the correlation heuristic that presents robust cognitive difficulty (Sterman 2010). According to LL, which we could apply to the full time period or only to the R&D

stage, by year 14, \$1.8B in total is committed by Firm B (\$800M in the R&D stage and the rest in released products), and \$1.4B in total is committed by Firm A (\$400M in the R&D stage and the rest in released products). In addition to the dynamics of the rivalry, both Firms A and B would need to align and synchronize their R&D output with their respective demand flows. If these firms were in the business of software, the R&D process of designing and developing the software program would present a lead-time synchronization constraint vis-à-vis its demand generation life-cycle. The awareness of and interest in the software would need to be generated in time for its release. Furthermore, future upgrades and maintenance efforts would need to be aligned with the quality (features, improvements) and frequency (timing) expectations of incremental releases (i.e., perhaps more frequent but requiring less lead time). Analogously, retaining key programmers knowledgeable about the product line and training new recruits in time would be required to maintain the level (stock) of expertise to service its development pipeline, i.e., the market presence. To summarize, the difference between the supply and demand flow cycle extends the strategic planning horizon to at least the longest lead-time.

We use the resource-time space introduced earlier to depict the path traveled by both firms. As alluded to in Chapter 3, the shortest path between the starting point (Products = 0, Year = 0) and the catch-up point (Product = 200, time = 14) would have been the green dashed line, as shown in Figure 8. Because of the R&D time constraint, i.e., the lead time required to develop a new product, both firms incur a 4-year delay. However, Firm B incurs an additional wait time of 5 years before embarking on its development. The path in the resource-time space traveled by Firm A is in blue and red for Firm B (Figure 8).

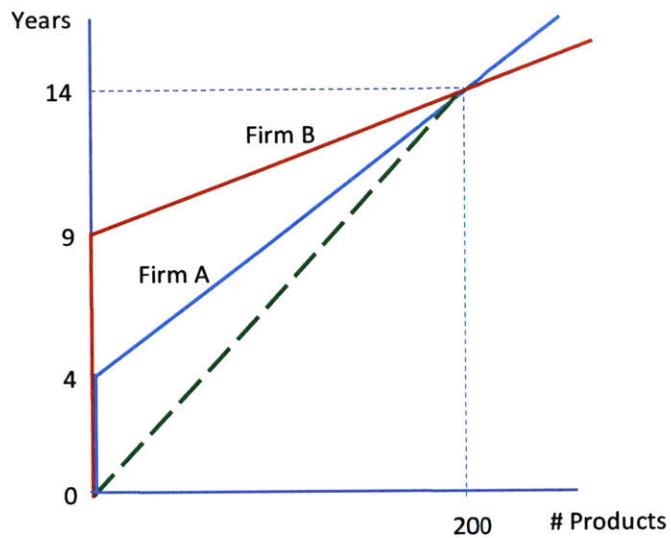


Figure 8. Firm A travels a shorter path in the resource-time space than its rival Firm B.

## Chapter 5 - Summary Discussion

We propose two additions to the cross-sectional view of the value chain. First, we propose that the cross-sectional view includes a causally linked set of resources - RBV with a known causal structure and the level of resources. Next, we add the time dimension to this view by introducing the flow of resources (changes in the level of resources over time) to complete the longitudinal view. The structural complexity of the value chain reflecting the number of the resource stocks and their relationships may very well be quite high, giving rise to the problem of dynamic complexity over time. There are robust cognitive limitations even for the simplest configuration of resource accumulation (Sterman 2010), (Cronin et al. 2009).

We have proposed applying the DSCM representation to construct the assembly node for applying the LL heuristic. We also discussed the resource-time space as a helpful construct for plotting a firm's evolutionary resource path.

The combination of the assembly view and LL allows us to mask the underlying dynamic complexity of the value chain, albeit at the cost of precision, by offering a simple, robust, and versatile heuristic. First, it allows us to define an abstract and largely arbitrary system boundary for the value chain or any part of it. This allows us to examine and apply the heuristic selectively to a resource or a set of resources at any segment within it. Second, at its core it offers a linear approximation for the relationship between time and resources in the value chain. The black box delineated by the system boundary is characterized by the aggregate level of resources contained within the boundary at any given time. The average flow of the resources through the boundaries over time then allows us to derive the average sojourn or residency time. As such, it establishes the average rate of flow as a proportionality constant between time and resources, effectively providing a conversion mechanism between these two dimensions to provide a meaningful relationship between "what" and "when." This mechanism allows for an approximate but, nonetheless, powerful foresight in determining the future state of the company's resource array based on the state of these resources in the present.

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