Simulation & Gaming
44(5) 624–644

DOI: 10.1177/1046878113503525
sag.sagepub.com

Modeling Tactical Product-Mix Decisions: A Theory-of-Constraints Approach

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Abstract

Notwithstanding the wide-spread inclusion of product-mix decisions in marketing simulation games, little theoretical work has been done to ensure that the algorithms driving them reflect current knowledge regarding product-mix strategy. Recent work based on relationship marketing theory has sought to address this problem strategically, focusing on the impact of demand correlation within the product mix. This article extends this line of research to a tactical level, using Goldratt's theory of constraints to address the impact of supply constraints on product-mix interactions. It shows how these factors can be incorporated into a standard simulation objective function.

Keywords

constraint-based product mix, demand correlation, Goldratt, linear programming, product mix, profitable product death spiral, relationship marketing, theory of constraints

Product-mix decisions are central to marketing strategy, and are a common feature of marketing simulation games. Nevertheless, they have received relatively little theoretical attention in the literature on simulation design. This is potentially problematic. Traditional simulation designs tend to be governed by marketing and accounting

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principles that fail to address key interactions among the demand and supply variables associated with various products in a company's product mix (Cannon, Cannon, & Schwaiger, 2012). By "interactions," we simply mean situations where demand and/or cost variables cause the decision to carry one product in the mix to influence the decision regarding another. Theory would suggest that these interactions are not only important, but in many cases, critical to profit-optimizing product-mix decisions.

Cannon et al. (2012) address this on a strategic level by modeling Rust, Zeithaml, and Lemon's (2000) "Profitable Product Death Spiral"—a phenomenon growing out of *relationship marketing* theory. It posits that consumers are motivated by a desire to purchase portfolios of products, rather than individual product purchases. Cannon et al. (2012) account for product-mix interactions by associating a desired portfolio of products to each segment of the market. Segment sales are based on the marketer's ability to strategically deliver the desired product mix.

Focusing on desired portfolios addresses product-mix interactions from a demand perspective. We would expect to find product-mix approaches that focus on supply-based interactions as well—conditions that would make certain combinations of products more attractive for a company to produce, based primarily on supply considerations. In fact, this is the case. The most common approach is also strategic, designing, or selecting products with shared costs, thus generating economies of scale. Over the years, however, a considerable literature has grown up around the application of Goldratt's (Goldratt & Cox, 1992) theory of constraints to product-mix decisions. This approach would modify the quantity of various products produced within the strategic mix, based on constraints in production capabilities and/or customer demand.

This article will build on Cannon et al.'s (2012) demand-side work with the Profitable Product Death Spiral, adding supply-side considerations from the theory of constraints. It will begin by casting these two approaches into a larger four-part typology. It will then briefly review the literature specifically focusing on the theory of constraints and product-mix decisions. Finally, it will discuss the incorporation of theory-of-constraints considerations into the simulation algorithm that determines the impact of product-mix decisions.

Approaches to Modeling Product-Mix Interactions

Notwithstanding the relative lack of attention given to the modeling of product-mix interactions, the literature suggests at least four basic theoretical approaches. We can label these according to the principal driver of product-mix decisions:

1. The *competitive interaction* approach, growing out of product positioning theory;
2. The *desired portfolio* approach, growing out of relationship marketing theory;
3. The *volume-oriented resource utilization* approach, growing out the theory of economies of scale;
4. The *constraint-based resource utilization* approach, growing out of the theory of constraints.

The Competitive Interaction Approach

One of the most elegant approaches to product-mix interactions is what we might call the competitive interaction approach. It grows out of positioning theory, where the attractiveness of a product to a consumer segment depends on the distance of the product (as determined by its attributes) from the segment's ideal product (Johnson, 1971). A company's selection of products entails a careful balance of position, where products within the mix are distant enough from each other to minimize cannibalism, but close enough to avoid gaps that might be exploited by competitive entries (Teach, 2008).

Figure 1 presents a "positioning map" to illustrate the approach. The axes represent benefit dimensions by which the attributes of products may be matched to the attributes desired by different groups of customers. For instance, if the map represented the automobile market, the Y-axis might represent economy and the X-axis luxury. The circles represent segments, or groups of customers who prefer the same type of product. Using our automobile example, Segment 1 might represent a group of consumers that prefers a moderately economical, moderately luxurious car, such as the Ford Fusion, while Segment 2 might represent consumers that prefer a more luxury-oriented car such as a Lincoln MKS.

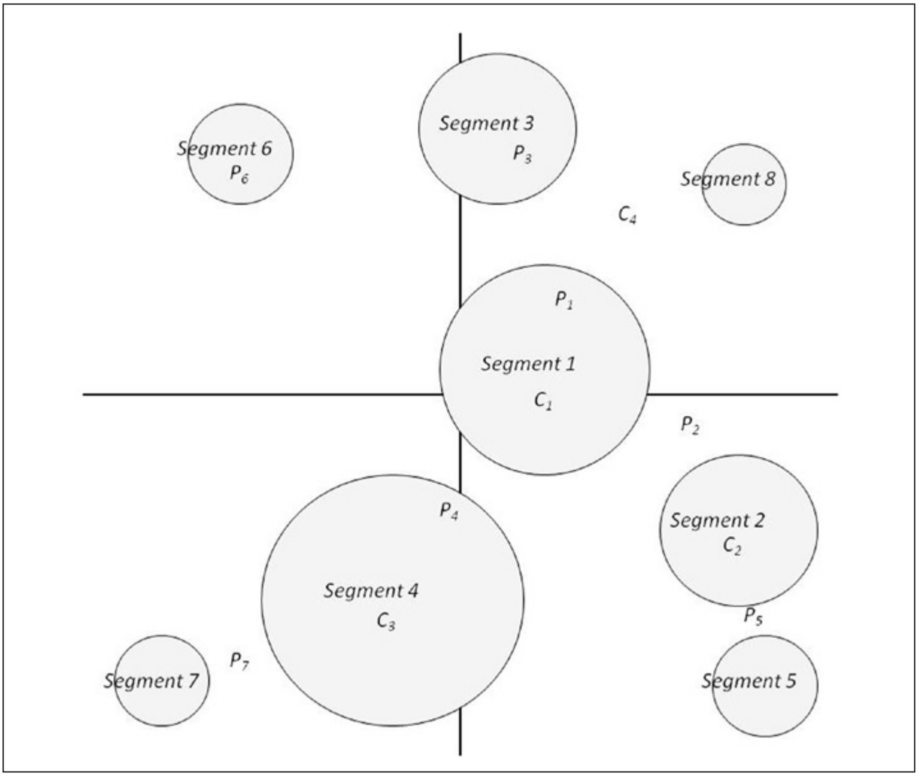

Figure 1. A positioning map illustrating the competitive interaction approach.

The subscripted *P*s represent various cars a company might offer in its product mix, while the *C*s represent competitive offerings. The term *competitive interaction approach* comes from the effect competition has on a company's product-mix strategy. For instance, note that C_1 is firmly established to address the needs of Segment 1. P_1 is positioned to compete in Segment 1, while also preempting Segment 1 sales to C_4.

This competitive interaction approach has been institutionalized in simulation design through the use of a multiattribute distance measure that determines unit demand (Teach, 1984, 1990). The closer a product is to the ideal point of a segment, the more preference members of the segment will have for the product. Segment size and preference are used to compute unit demand, which is then combined with price and costs to determine the profit contribution by market segment for each product in the portfolio (Gold, 2005).

The Desired Portfolio Approach

As noted earlier, Cannon et al. (2012) draw on relationship marketing theory to develop a second approach, what we might call the desired portfolio approach. Specifically, they use Rust et al.'s (2000) concept of the "Profitable Product Death Spiral" to suggest that the competitive interaction approach might result in suboptimal long-term profitability if consumers who buy one product from a company expect the company to offer other complementary products as well.

The Death Spiral occurs when managers seek to optimize profit by continually pruning low-margin products—that is, those with inferior competitive positions—in favor of those with higher contributions. Presumably, this would leave only the most profitable products in the mix, thus increasing the overall company profitability. However, in a relationship marketing environment, where profitability depends on selling bundles—desired portfolios—of products to the same consumers, product interactions become especially important. Rust cites the example of a textbook that was selling well, accompanied by a readings book that was not. The publisher dropped the readings book, but in the process, it alienated the textbook adopters who had structured their courses around use of the readings book as well. While this was not the majority of adopters, it was a large enough proportion to substantially lower sales of the original textbook (Rust et al., 2000).

Note that the problem is not really with marketing strategy per se, but with the product-mix decision algorithm that drives it. The competitive interaction approach relies on product profitability as its product-mix selection algorithm. Product profitability is measured by unit contribution margin (unit revenue minus unit variable cost). Although seeking to maximize contribution margin is seemingly a logical approach, the unintended consequence of maximizing product profitability while ignoring product interactions can be the Profitable Product Death Spiral, as Rust et al. (2000) describe it. That is,

- The company improves profitability by eliminating unprofitable products/services;

- The elimination of unprofitable products reduces the overall value of the product portfolio offered to customers;
- Lower value drives customers away and lowers profits;
- Lower profits increase pressure to make further cuts in an effort to bring profitability back up to targeted levels (Rust et al., 2000, p. 26).

The problem could be avoided by simply making customers rather than products the unit of measurement when calculating profit (Cannon & Cannon, 2008). The Death Spiral effect is created, in part, when demand for products is correlated. That is, a customer prefers products in combination rather than individually (hence, product demand for a product decreases as products are removed from the portfolio). Product demand correlation is a function of customer preferences and in fact, may be the major factor that differentiates customer segments. By using customers as the unit of analysis, managers implicitly account for product demand correlation, avoiding the Profitable Product Death Spiral.

The Volume-Oriented Resource Utilization Approach

Consistent with the aforementioned need for a more customer-oriented approach, Rust et al. (2000) address the product-mix problem from the perspective of relationship marketing theory. This is appropriate for companies whose key investments are customer-related rather than product-related (Cannon & Cannon, 2008). For instance, it might be much more appropriate for a retailer. However, the contrast suggests a company that is heavily invested in technology or manufacturing would take a different approach.

The approach would still look at potential interactions among products within the product mix. The interactions would be based on shared costs as opposed to the shared demand that characterized the desired portfolio approach. The sharing favors products that have common components and manufacturing processes, thus drawing on the economic theory of economies of scale. Here volume is king, as suggested by the label, the volume-oriented resource utilization approach.

Returning to our automobile example, a company such as Chrysler might have a compelling reason to increase its presence in the small, economy car segment of the market. However, Chrysler's technological and product expertise may be in larger cars and trucks, thus reducing the potential economies of scale available by sharing current technology and production capabilities with new small-car development and production activities. This would suggest Chrysler adopt a strategy of either omitting small cars from the product mix or joining forces with a company that possesses production and design strengths in small cars to achieve the required economies.

The economies of scale express themselves through a lower average unit cost. The actual costs are allocated to individual products, either as indirect costs, or more recently, as activity-based costs (Draman, Lockamy, & Cox, 2002). The indirect-costing method seeks to apportion overhead costs to the various products through some kind of allocation basis. Activity-based costing uses a two-stage allocation, where overhead costs are first traced to specific activities, and then the cost of each activity is allocated to products, based on how each of the products use the activities. The volume-oriented resource utilization approach manages the product mix by seeking products that share activities that comprise significant components of product overhead costs and are subject to significant economies of scale.

The Constraint-Based Resource Utilization Approach

The literature on theory of constraints suggests a different approach for optimizing resource utilization, resulting in a radically different approach to product-mix decisions—what might be called the constraint-based resource utilization approach. The theory of constraints grows out of the work of Eliyahu Goldratt (Goldratt & Cox, 1992), who studied manufacturing processes and found that standard cost-accounting procedures led companies to focus on cost-reduction, even when it actually increased costs and lowered profits.

The contribution of the theory of constraints is in its focus on throughput rather than volume (Chakravorty & Verhoeven, 1996). By throughput, we mean the amount of contribution margin that is generated by moving products through the value chain, as opposed to focusing on economies of scale, as is characteristic of volume-oriented resource utilization approach. Constraints are anything in the system that limits throughput. In the real world of business, every system is subject to a host of potential constraints—volume limitations from machine capacity or suppliers, availability of trained labor, raw materials, and so forth. However, the theory of constraints suggests that managers only focus on the most limiting constraint when maximizing throughput.

To illustrate the constraint-based resource utilization approach, consider a simple example of a company that makes two products. Both sell for US$100 and are made in the same factory with the same variable production inputs (Materials X and Y).[1] Product A uses three units of Material X, costing US$10 per unit, and one unit of Material Y, costing US$20 per unit. Product B uses one unit of Material X and three units of Material Y.

All else being equal, the company would produce both Products A and B. Both have a positive contribution margin (US$100 − 3 × US$10 − 1 × US$20 =) US$50 and (US$100 − 1 × US$10 − 3 × US$20 =) US$30 per unit, respectively. Without considering demand or production constraints, the company would shift production to Product A, because it provides a higher product contribution margin. By contrast, suppose a constraint exists in the availability of Material X. The company would shift production to Product B because it can make 3 times as many units given the same amount of Material X. To illustrate, suppose the company has access to 3,000 units of Material X. It can produce 1,000 units of Product A, yielding a profit contribution of (US$50 × US$1,000 =) US$50,000, or it can produce 3,000 units of Product B, yielding a contribution of (US$30 × 3,000 =) US$90,000.

The point is that the theory of constraints shows the impact of the constraint on overall contribution margin for each potential product mix. This allows managers to select the product mix that will maximize contribution margin, given the production process and available demand. This is true whether the system's constraint is a limited resource, available material, or demand itself. For instance, in our example, we see how a constraint in Material X shifts production from Product A to Product B. If no materials constraint existed, but a demand constraint on Product A, the company would produce what demand would bear of Product A, and then switch to production of Product B. While actual product-mix problems are usually much more complicated, the example illustrates the basic principle underlying the constraint-based resource utilization approach to modeling product-mix interactions.

The constraint-based resource utilization approach deals with the reality of current supply, production, and demand limitations. A company uses the competitive interaction, desired portfolio, and/or the volume-oriented resource utilization approach to develop a product mix that is designed to strategically exploit intermediate to long-term market conditions. The constraint-based approach addresses the fact that actual resource availability and demand inevitably deviate from plan, thus creating constraints that a company must address by adjusting the product mix to maximize profit.

A Brief Summary of the Literature

We have already suggested that the literature can be roughly divided into four basic approaches to developing product-mix simulation algorithms: (a) the competitive interaction approach, (b) the desired portfolio approach, (c) the volume-oriented resource utilization approach, and (d) the constraint-based resource utilization approach. The first three approaches have already been addressed in the literature on simulating and gaming.

While the fourth (constraint-based resource utilization) approach has not been addressed in the simulation and gaming literature, the literature does contain a number of studies discussing how the principles of the theory of constraints might be incorporated into a simulated business environment (Chakravorty & Verhoeven, 1996; Jordan, 2006; Mukherjee & Wheatley, 1999; Taylor, Jackson, Jackson, & Seanard, 2007). These provide useful background, but do not address the specific problem of product-mix interactions.

Looking beyond the literature on simulation and gaming, we find a number of studies addressing product-mix decisions. For instance, searching the ProQuest database for "product mix" AND "theory of constraints," we found 19 studies. With the exceptions of 3 expositional studies on the merits of applying the theory of constraints in making product-mix decisions (Hilmola, 2001), how to improve its application (Koksal, 2004), and a case study for teaching the constraint-based resource utilization approach (Brewer, Campbell, & McClure, 2000), the studies were split evenly between articles addressing the use of mathematical programming to implement optimal theory-of-constraint solutions and studies comparing constraint-based resource utilization approaches with volume-oriented resource utilization approaches to product-mix formulation.

The mathematical programming articles address a simulation game player's perspective—how to develop an optimal product mix, given types of resource constraints. A review of these articles could be useful in the debriefing process of the game, but it is beyond the scope of this article.

The articles comparing constraint-based versus volume-oriented resource utilization approaches are useful in providing a rationale for this article. Three of them found that throughput accounting (the constraint-based resource utilization approach) appeared to be superior to conventional allocation approaches (Draman et al., 2002; Low, 1992; Patterson, 1992). The others suggest various improvements in the constraint-based resource utilization approach, either through some form of integration with activity-based accounting (Kee & Schmidt, 2000; Lea & Fredendall, 2002; Sheu, Chen, & Kovar, 2003; Yahya-Zadeh, 1998), or through a new approach altogether (Tsai, Lai, Tseng, & Chou, 2008). Spoede, Henke, and Umble (1994) suggest that activity-based accounting should be used to generate the data for a constraint-based approach.

Overall, the extant evidence appears to support the basic arguments underlying the constraint-based resource utilization approach sufficiently, at least, to justify addressing it in a simulation game environment. This failing, the introduction of constraints into a simulation game environment parallels what one would encounter in the real world, regardless of how students choose to address them.

Simulating a Constraint-Based Product Mix

Cannon and Schwaiger (2005) suggest that game development would be more efficient if it built upon a standard platform whenever possible, thus avoiding unnecessary duplication and economizing on common learning. They recommend Gold's (2005) system-dynamic model as such a platform, what they refer to as the "Gold standard." We will take this approach, casting the constraint-based resource utilization approach as a modification of Gold's standard algorithm.

One of the advantages of Gold's algorithm is that it separates demand and cost functions, thus enabling the designer of a marketing simulation to easily incorporate both demand- and supply-driven product interactions into the algorithm that determines the payout of various marketing-mix combinations. Gold's original algorithm was designed to address what we have referred to as the competitive interaction approach. It expresses the effectiveness of the product mix as a function of product-market fit, expressed through D_j, or the distance between a company's product offering and the ideal for segment j (Teach, 1984, 1990, 2008). Cannon et al. (2012) use the same basic algorithmic mechanism to address the desired portfolio approach, treating each desired portfolio as a kind of "pseudo-product."

A simulation would typically model one approach or the other, seeking to school game participants in either *product positioning* or *relationship marketing* theory, but not both simultaneously. However, we see no reason why a simulation could not accommodate both. The two approaches could be integrated by simply weighting the desirability of each product in a segment's preferred portfolio by the relative strength of its position, as determined by the competitive interaction approach.

We find even greater compatibility in modeling supply-side product-mix interactions. Gold's discussion of cost is based on the assumption that production will be internal to the simulated firms (as opposed to outsourced), and that costs will be a nonlinear function of amounts of labor, materials, and capital equipment investment. The nonlinearity of cost factors provides a mechanism for incorporating economies of scale into the cost function. In order to implement the volume-oriented resource utilization approach, the simulation designer need only give participants the option of sharing resources across products in order to increase economies of scale.

In concept, the constraint-based resource utilization approach can be implemented in the simulation by simply introducing constraints into the cost equation, either by limiting the availability of materials or labor, or by converting them to step functions through the introduction of expensive outside suppliers, the utilization of less efficient machinery, or some other plausible scenario. Any of these options would also accommodate the volume-oriented resource utilization approach.

In practice, the art of designing an effective simulation is to make it as simple as possible, while still capturing the essence of the phenomenon being modeled. Our suggestion to the simulation designer, then, would be, all else being equal, to focus on one approach or the other, depending on the objectives of the simulation. The obvious exception would be an advanced simulation game, where participants are well versed in the theoretical bases for product-mix interactions, and the objective is to experience how they work together in a complex environment.

Our purpose here is to discuss a simple method for modeling the impact of resource constraints on product-mix interactions—for implementing the constraint-based resource utilization approach. In order to make our discussion more concrete, we include as an appendix a sample scenario that illustrates the competitive interaction, desired portfolio, and volume-oriented resource utilization approaches in conjunction with the kind of constraint-based problem we might want participants to confront. Of course, the three alternative approaches are strategic rather than tactical in nature. That is, they present guiding principles, the implementation of which would take long-term constraints into account and plan for the avoidance of any short-term constraints. Citing them in the appendix is meant to provide a point of comparison, illustrating why the constraint-based approach is superior for tactical decision-making.

Putting the Theory-of-Constraints in Perspective: An Integrative Approach

We began by suggesting that the literature can be roughly divided into four basic approaches to developing product-mix simulation algorithms: (a) the competitive interaction approach, (b) the desired portfolio approach, (c) the volume-oriented resource utilization approach, and (d) the constraint-based resource utilization approach. This is not meant to imply that they are mutually exclusive. Indeed, we argue that they should all be addressed in a comprehensive marketing simulation. Their individual relevance is in the fact that, from a managerial perspective, their relative importance changes with the situation being portrayed by the simulation. The competitive interaction approach tends to be most important in situations in which consumers evaluate products individually with relatively little regard to their relationship to other purchases. By contrast, the desired portfolio approach is most relevant when products' demand interacts, either through a need for compatibility or purchase convenience. However, both of these approaches would be important in cases where consumers think of a group of products and services as if they were a single product (as would be the case for a retailer whose "product" is the total shopping experience). Cannon et al. (2012) address this by modifying Teach's (1984, 1990) distance algorithm to assess the relative attractiveness of groups of products as well as individual products to each segment of the market, feeding the resulting effects into Gold's (2005) demand algorithm.

In similar fashion, Gold's (2005) cost algorithm can be readily adapted to accept shared activity costs, thus enabling the simulation to accommodate the volume-oriented resource utilization approach. Of course, the level of detail incorporated into the design would depend on the purpose of the simulation. This approach is most relevant for manufacturing firms or simulations whose objective is to school participants in the impact product design and cost structures have on marketing effectiveness.

The constraint-based resource utilization approach is compatible with all of the other three approaches. As long as a simulation has constraints in any given decision period, game participants will be faced with utilization decisions. The example portrayed in Appendix Tables A1 to A4 addresses product allocations in conjunction with the desired portfolio approach, but the same principles would apply production constraints relating to individual products (competitive interaction approach). The production constraints, in turn, could well be related to strategic sourcing or production decisions made in conjunction with the volume-oriented resource utilization approach. In this article, we focus on product-mix decisions, but the same principles could be applied to sales-force training and sales-call allocations to promote the products in the mix.

Summary and Conclusion

At the most general level, the purpose of this article has been to demonstrate the importance of considering alternative theories when modeling the consequences of product-mix decisions in business simulations. The traditional approach to simulation design is to simply add products to the simulation, each with its own demand and cost functions, leading to a corresponding profit function. If the purpose of the product-mix decisions is to address product-mix strategy, rather than simply adding complexity to the game by giving players more products to manage, a game could introduce some kind of constraint, such as a limit in the number of brands that may be launched, or some kind of budget constraint. This would force them to make a strategic choice among products. The aforementioned theories address the criteria successful game participants would use to make these choices. The criteria are linked to successful game performance by the algorithms underlying what we have characterized as the competitive interaction, desired portfolio, volume-oriented resource utilization, and constraint-based resource utilization approaches.

Given the centrality of production and associated costs to traditional business models, the most obvious approach is volume-oriented resource utilization. This focuses attention on issues of cost structure and product design as criteria for product-mix strategy—what Kotler (Kotler & Keller, 2012) refers to as a production and product orientation. This is most appropriate for simulations that address markets with relatively well-established product categories, where competitors tend to compete head-on using a strategy of product differentiation.

With the ascendency of market segmentation and positioning in the practice of marketing, simulation designers have sought a more customer-oriented framework. Teach (1984, 1990, 2008) addresses this through what we have characterized as the competitive interaction approach. It draws on positioning theory to introduce issues of competitive encroachment and cannibalism into the product-mix decision. While this represents a major step forward in simulation design, it fails to address the growing movement toward relationship marketing, where marketers seek to lower transaction costs by providing loyal customers with shopping convenience, offering them their desired portfolios of products.

Cannon et al. (2012) built on Teach's positioning approach by modeling Rust et al.'s (2000) Profitable Product Death Spiral concept. The Death Spiral drives to the weakness in the competitive interaction approach, explaining how the interactions in product demand cause the competitive interaction approach to result in sub-optimal profit contribution. The response—what we have referred to as the desired portfolio approach—grows out of consumers' desire to purchase assortments rather than individual products. This, too, represents a significant step forward in simulation design, addressing the shift from product-centric to customer-centric marketing (Rust et al., 2000). However, it also signals a change in the unit of analysis that a company would use for managerial accounting, from products to customers (Cannon & Cannon, 2008).

Shifting accounting focus from products to customers is strategically vital in a simulation that seeks to reward market responsiveness and relationship marketing. However, it does not obviate the need to look at supply- as well as demand-related factors in product-mix decisions. Any customer-driven marketing-mix decisions would necessarily consider costs as well as customer needs. This can be done by applying the principles of volume-oriented resource utilization, either designing strategically selected products with shared components to achieve economies of scale, outsourcing to suppliers who already have these economies, or more commonly, a combination of both.

We argue that constraint-based resource utilization is also important when implementing a strategically designed product mix. Marketing strategy is always based on the constraints that appear to be obvious—limited demand, customer tastes, technological capabilities, financial limitations, and so forth. The strategic approaches we have discussed are designed to take these into account and maximize profit within their constraints. The constraint-based resource utilization approach provides a method for responding to unrealized or unanticipated constraints that inevitably occur as the strategic plan is implemented—such as production limitations, supply shortages, strikes, unanticipated plant closings, customer boycotts—anything that is the most limiting constraint that impedes throughput (contribution margin) in the strategic product mix. The constraint-based resource utilization approach highlights the effects of the most limiting constraint on the ability to generate contribution margin for the entire system. If the most limiting constraint is resolved, another takes its place, so that the marketing strategy may need to change in order to maximize throughput given the new constraint. While a simulation game environment would not typically confront students with a continual set of unanticipated constraints, confronting students with the effects of the typically unrealized constraints such as a production bottleneck or a limited supply of a raw material, provides them with a valuable opportunity to apply theory of constraints methodology. This would enable them to address the kinds of problems they are likely to encounter in the real world, but for which conventional product-mix approaches leave them inadequately prepared.

As a final comment, we should again note the relative dearth of research in the modeling of product-mix decisions. Until recently, product-mix decisions have been virtually ignored in the literature on simulation design notwithstanding their critical role in business success. While we believe the framework summarized in this article—the competitive interaction, desired portfolio and volume-oriented resource utilization approaches to product-mix strategy—is robust as a method of classification, each approach supports any number of lower-level strategies. For instance, within the desired portfolio approach, Shapiro (1991) suggests a strategy of "cascading demand." Cannon, Cannon, and Andrews (2010) model it to demonstrate the potential problems with exploiting captive consumer relationships. Shapiro describes a number of other strategies that have yet to be modeled. In the category of volume-oriented resource utilization approaches, Anderson's (2006) book, *The Long Tail*, suggests dramatic changes in the way economies of scale operate in our evolving market. How should we model these?

Distinguishing between strategic and tactical approaches, as we have in this article, expands the potential range of work still further. We have suggested a constraint-based resource utilization approach. What other tactical approaches are available? How should they be modeled?

Beyond any specific methodological contribution this article makes, we hope that it will also serve as a call to arms. It suggests a research agenda whose topic is particularly relevant in a market where effective product-mix decisions are becoming an increasingly important element of marketing success.

Appendix

Sample Illustration of a Constraint-Based Approach

Imagine a simple case where three market segments (1, 2, and 3) provide demand for three products (A, B, and C). For simplicity, let us assume no product demand correlation (demand for one product does *not* decrease if other products are not offered). The contribution margin per unit (price less unit variable cost) associated with each product is described in the first row of Table A1. For simplicity, we can assume that product prices do not vary across segments, and that the products are produced by the company using some combination of Inputs X and Y. These conditions can be readily handled through Gold's (2005) standard algorithm.

Table A1. Desired Product Portfolios With Contribution Margin by Product and Segment.

	1	2	3	4	5	6	7	8
	Product A	Product B	Product C	Product contribution	Cost to serve	Segment contribution	Input X required	Input Y required
Unit contribution	US$100	US$45	US$30					
Segment information								
Segment 1	1,000	2,300	2,750	US$286,000	US$256,000	US$30,000	13,650	9,350
Segment 2	300	0	1,000	US$60,000	US$40,000	US$20,000	2,200	1,600
Segment 3	0	200	1,000	US$39,000	US$50,000	(US$11,000)	1,600	1,400
Resource requirements (per product)								
Input X	4	3	1					
Input Y	2	2	1					
Production constraints		Capacity of Input X = 15,000 Input X fixed cost = US$5,000				Capacity of Input Y = 15,000 Input Y fixed cost = US$5,000		

A product manager using the competitive interaction approach would add products to its portfolio in order of product profitability (in terms of unit contribution margin). It is evident that the most profitable product is A, followed by B and C, respectively.

The rows under "Segment Information" present the quantities demanded by each segment of each of the three products. Column 5 provides the customer investment required to serve each customer segment. This investment represents fixed advertising/promotion expenses specific to and required for serving each segment. For example, a fast-food restaurant may invest fixed advertising expense targeting the "children" segment by associating a "kid's meal" with the latest children's film. Column 4 reports the total product contribution margin by segment. Column 6 reports the total contribution margin provided by each segment. The last two columns summarize the total Inputs X and Y required to service each segment.

Following the logic of the desired portfolio approach, game participants would identify the segments they wish to target, and address them by including products within the company's mix that meet the needs of each target's desired portfolio. In our example, a product manager using the desired portfolio approach would choose to serve Segments 1 and 2, but not Segment 3 (Segment 3 yields a negative contribution margin).

Finally, the bottom rows of Table A1 report the quantities of Inputs X and Y that are required to produce a unit of each product, the total supply of Inputs X and Y available to the firm, and the fixed cost investment required to acquire and use Input X and Input Y capacity. This investment represents manufacturing expenses specific to each production input resource. For example, a manufacturer may incur custom tooling expense to convert inputs into end-products.

Following the logic of the volume-oriented resource utilization approach, game participants would produce the greatest quantity of product possible in order to minimize unit product costs by distributing fixed production costs over production quantity. In our example, a product manager using the volume-oriented approach would manufacture Product C because it requires the least amount of Inputs X and Y per unit produced, thus allowing greater production volume. Product C would be followed by Product B, then followed by Product A, in order of priority. The short-term decision would be part of a long-term strategy that would seek to break demand constraints, invest in new production capacity, and seek new technologies for increasing economies of scale.

A product manager using the constraint-based resource utilization approach would follow a two-step process. First, the manager would determine the system constraint. In this example, we calculate and report the quantity of Inputs X and Y required to service the demand for all products in Table A2. We conclude that Input X is a potential system constraint because it requires 17,450 units of Input X (2,450 units more than Input X capacity) to satisfy all demand. However, remember that according to a desired portfolio approach, Segment 3 would not be served given it is unprofitable (US$11,000 loss). Dropping the segment changes the demand load applied to the system, as shown in Table A3. We see that the supply of Input X is still the system constraint regardless of whether we drop Segment 3 because it requires 15,850 units of Input X (850 units more than Input X capacity) to satisfy Segments 1 and 2 demand. As such, the supply of Input X constrains the system even if we apply a desired portfolio approach.

Table A2. Evaluating the System Constraint.

	Quantities demanded		
	Product A	Product B	Product C
Segment 1	1,000	2,300	2,750
Segment 2	300	0	1,000
Segment 3	0	200	1,000
Total	1,300	2,500	4,750
Input X	1,300 × 4 + 2,500 × 3 + 4,750 × 1 = 17,450 (capacity = 15,000)		
Input Y	1,300 × 2 + 2,500 × 2 + 4,750 × 1 = 12,350 (capacity = 15,000)		

Table A3. Evaluating the System Constraint After Dropping Segment 3.

	Quantities Demanded		
	Product A	Product B	Product C
Segment 1	1,000	2,300	2,750
Segment 2	300	0	1,000
Total	1,300	2,300	3,750
Input X	1,300 × 4 + 2,300 × 3 + 3,750 × 1 = 15,850 (capacity = 15,000)		
Input Y	1,300 × 2 + 2,300 × 2 + 3,750 × 1 = 10,950 (capacity = 15,000)		

The second step to the constraint-based resource utilization approach is to calculate contribution margin per unit of constrained resource. Table A4 shows the contribution margin per unit of product in row one, Input X requirements per product in row two and contribution margin per unit of Input X in row three. Product C provides the most contribution margin per unit of Input X, followed by Products A and B, respectively. This suggests that, given Input X is the constrained resource, the product manager should produce enough Product C to satisfy demand, followed by Products A and B until the constrained input X is exhausted.

Table A4. Profit Contribution by Product and Constrained Resource.

	Product A	Product B	Product C
Contribution margin per unit	US$100	US$45	US$30
Input X required per product	4	3	1
Contribution margin per unit of Input X	US$25	US$15	US$30

The constraint-based resource utilization approach to designing product-mix interactions explicitly takes the effects of the system's constraint into account in making production decisions. The production results from the competitive interaction, desired portfolio, and volume-oriented resource utilization approaches are still affected by the constraint although the constraint is not explicitly considered in the decision-making for those approaches. We find an old saying among theory of constraints proponents to the effect that: "You can ignore the constraint of your system, but it will not ignore you. In fact, it will control you."

To put the differences between approaches into perspective, let's consider the net profit generated if managers were to focus on contribution margin by product, on contribution margin by segment, or on maximizing production volume. Looking first at product contribution (competitive interaction approach), production priority would be on Product A, then B, then C, given the product contribution margins of US$100, US$45, and US$30 per unit, respectively. This means that the production plan would include 1,300 units of Product A (consuming 5,200 of Input X) → US$130,000 contribution margin (1,300 units × US$100 per unit). It would include 2,500 units of Product B (consuming 7,500 of input X) → US$112,500 contribution margin (2,500 units ×

US$45 per unit). Finally, the remaining Input X (15,000 − 5,200 − 7,500 = 2,300) would be used to produce 2,300 units of Product C (consuming 2,300 of Input X) → US$69,000 contribution margin (2,300 units × US$30 per unit). The total product contribution margin would be (US$130,000 + US$112,500 + US$69,000 =) US$311,500. Subtracting the fixed production cost and the cost of serving each segment, the net profit would be (US$311,500 − US$5,000 − US$5,000 − US$256,000 − US$40,000 − US$50,000 =) a loss of US$44,500.

If managers choose not to serve Segment 3 (it yields a negative segment margin) while focusing on maximizing product contribution, the production plan would include 1,300 units of Product A (consuming 5,200 of Input X) → US$130,000 contribution margin (1,300 units × US$100 per unit). It would include 2,300 units of Product B (consuming 6,900 of input X) → US$103,500 contribution margin (2,300 units × US$45 per unit). Finally, the remaining Input X (15,000 − 5,200 − 6,900 = 2,900) would be used to produce 2,900 units of Product C (consuming 2,900 of Input X) → US$87,000 contribution margin (2,900 units × US$30 per unit). The total product contribution margin would be (US$130,000 + US$103,500 + US$87,000 =) US$320,500. Subtracting the fixed production cost and the cost of serving segments 1 and 2, the net profit would be (US$320,500 − US$5,000 − US$5,000 − US$256,000 − US$40,000 =) a net profit of US$14,500.

If managers focus on contribution margin per segment (desired portfolio approach), production priority would be serving Segment 1, with a segment contribution of US$30,000, and then Segment 2, with a segment contribution of US$20,000. They would not serve Segment 3, with a segment contribution of negative US$11,000. Segment 1 demand consumes 13,650 of Input X (4 × 1,000 + 3 × 2,300 + 1 × 2,750), leaving 1,350 of Input X to satisfy Segment 2 demand. Producing 1,000 units of Product C and 87 units of Product A for Segment 2, the segment now generates product contribution of (1,000 units × US$30/unit + 87 units × US$100/unit =) US$38,700.[2] Subtracting the cost of service for the segment (US$40,000), the result is a US$1,300 loss from Segment 2. The product manager would choose to only serve Segment 1 demand resulting in a net profit of US$20,000 after subtracting fixed production cost (US$5,000 + US$5,000) from Segment 1 contribution.

If managers focus on maximizing volume (volume-oriented resource utilization approach), production priority would be on Product C, then B, then A, given Product C consumes the least quantity of Inputs X and Y, followed by Products B and A. This means that the production plan would include 4,750 units of Product C (consuming 4,750 of Input X) → US$142,500 contribution margin (4,750 units × US$30 per unit). It would include 2,500 units of Product B (consuming 7,500 of input X) → US$112,500 contribution margin (2,500 units × US$45 per unit). Finally, the remaining Input X (15,000 − 4,750 − 7,500 = 2,750) would be used to produce 687 units of Product C (consuming 4 × 687 = 2,748 of Input X) → US$68,700 contribution margin (687 units × US$100 per unit). The total product contribution margin would be (US$142,500 + US$112,500 + US$68,700 =) US$323,700. Subtracting the fixed production cost and the cost of serving each segment, the net profit would be (US$323,700 − US$5,000 − US$5,000 − US$256,000 − US$40,000 − US$50,000 =) a loss of US$32,300.

If managers choose not to serve Segment 3 (it yields a negative segment margin) while maximizing production volume, the production plan would include 3,750 units of Product C (consuming 3,750 of Input X) → US$112,500 contribution margin (3,750 units × US$30 per unit). It would include 2,300 units of Product B (consuming 6,900 of input X) → US$103,500 contribution margin (2,300 units × US$45 per unit). Finally, the remaining Input X (15,000 − 3,750 − 6,900 = 4,350) would be used to produce 1,087 units of Product C (consuming 4 × 1,087 = 4,348 of Input X) → US$108,700 contribution margin (1,087 units × US$100 per unit). The total product contribution margin would be (US$112,500 + US$103,500 + US$108,700 =) US$324,700. Subtracting the fixed production cost and the cost of serving Segments 1 and 2, the net profit would be (US$324,700 − US$5,000 − US$5,000 − US$256,000 − US$40,000 =) a net profit of US$18,700.

Contrast the net profit generated using a competitive interaction, desired portfolio, or volume-oriented resource utilization approach with net profit generated using a constraint-based resource utilization approach. Recall that the product manager would choose to produce Product C, then Product A, followed by Product B. These choices maximize the use of the constrained resource (Material X) to generate contribution margin. Again, managers would not choose to serve Segment 3, because the potential contribution (US$39,000) is still insufficient to cover the cost of service (US$50,000). The manager would produce 3,750 units of Product C (consuming 3,750 of input X) → US$112,500 contribution margin; 1,300 units of Product A (consuming 5,200 of Input X) → US$130,000 contribution margin; and 2,016 units of Product B (consuming 6,048 of Input X) → US$90,720 contribution margin. Total product contribution margin would be (US$112,500 + US$130,000 + US$90,720 =) US$333,220. Net profit would be (US$333,220 − US$5,000 − US$5,000 − US$256,000 − US$40,000 =) US$27,220 by serving both Segments 1 and 2.

Note that the competitive interaction approach, concentrating on the highest product contribution margin (without serving the unprofitable Segment 3), would result in a net profit of US$14,500. The desired portfolio approach, concentrating on the highest contribution per market segment, makes a net profit of US$20,000. The volume-oriented resource utilization approach, concentrating on maximizing volume (without serving the unprofitable Segment 3), makes a net profit of US$18,700. Although the results from these approaches are limited by the system's constraint, the constraint is not explicitly considered in the decision-making process. Note that given the constraint, the constraint-based resource utilization approach generates the highest net profit, US$27,220.

In fairness to our comparison, our assumption that restricting production of one product will not decrease the demand of another violates the assumptions behind the desired portfolio approach. If our objective were to create a simulation that included both the effect of desired portfolios and constrained resources, we would model the losses due to demand correlation using the algorithm suggested by Cannon et al.(2012). Students would be left to balance the losses in demand resulting from inferior product portfolios against the cost savings resulting from the more efficient utilization of constrained resources.

In complicated product input and pricing settings, simulation participants might utilize the constraint-based resource utilization approach in many ways. Mixed integer linear programming is one tool that players might use to employ the approach to arrive at the profit-maximizing product mix. Mixed integer linear programs are supported by various software solutions, for example, Excel Solver, LINDO Callable Library, and What's Best, and described in prior literature (Gomory, 1963, 1965; Manne, 1960a, 1960b, 1960c). The example lends itself to such a solution.

Let A_m, B_m, and C_m represent the quantities of Products A, B, and C to be produced for each segment m. Following the example, m can take the value of 1, 2, or 3 referencing segments 1, 2, and 3. Let Z_m be a segment indicator variable equal to 1 if a segment is targeted (i.e., any amount of demand for a segment is served) and 0 if the segment is not targeted. The Mixed Integer Linear Program set up would be as follows:

Objective function:

Maximize segment contribution margin = $100\,A_1 + 100\,A_2 + 100\,A_3 + 45\,B_1 + 45\,B_2 + 45\,B_3 + 30\,C_1 + 30\,C_2 + 30\,C_3 - 256000\,Z_1 - 40000\,Z_2 - 50000\,Z_3$

Subject to:

Demand constraints

$A_1 - 1{,}000\,Z_1 \leq 0$
$A_2 - 300\,Z_2 \leq 0$
$A_3 - 0\,Z_3 <= 0$
$B_1 - 2{,}300\,Z_1 \leq 0$
$B_2 - 0\,Z_2 \leq 0$
$B_3 - 200\,Z_3 \leq 0$
$C_1 - 2{,}750\,Z_1 \leq 0$
$C_2 - 1{,}000\,Z_2 \leq 0$
$C_3 - 1{,}000\,Z_3 \leq 0$

X supply constraint: $4\,A_1 + 4\,A_2 + 4\,A_3 + 3\,B_1 + 3\,B_2 + 3\,B_3 + 1\,C_1 + 1\,C_2 + 1\,C_3 \leq 15{,}000$

Y supply constraint: $2\,A_1 + 2\,A_2 + 2\,A_3 + 2\,B_1 + 2\,B_2 + 2\,B_3 + 1\,C_1 + 1\,C_2 + 1\,C_3 \leq 15{,}000$

Where

$A_m \geq 0$ for all m
$B_m \geq 0$ for all m
$C_m \geq 0$ for all m
$Z_m = 0$ or 1 for all m

The objective function maximizes the contribution of each product per segment while subtracting the customer investment required when entering a segment. The demand constraints ensure that the program does not produce more products than segment demand can support. The X and Y supply constraints ensure that the program does not consume more production inputs than are available to the firm. The final program constraints disallow negative production and define the segment integer variables.

Acknowledgments

The authors express sincere gratitude to Clinton Andrews (Wayne State University) for his contribution to an earlier version of this article.

Declaration of Conflicting Interests

The authors declared no conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Notes

1. In this illustration, we assume that all other production input costs do not vary proportionately with production activities. That is, they are "fixed" and therefore excluded from the contribution margin calculation.
2. Product C provides greater contribution margin per unit of Input X (US$30 per unit of Input X) than Product A (US$25 per unit of Input X). Therefore, given a strategy to serve Segment 2, a manager would choose to produce Product C before producing Product A. Note that this does not take into account any Segment 2 product demand correlation effects that may influence demand for either product.

References

Anderson, C. (2006). *The long tail: Why the future of business is selling less of more*. New York, NY: Hyperion Books.

Brewer, P. C., Campbell, R. J., & McClure, R. H. (2000). Wilson electronics (A) and (B): An ABC capstone experience. *Issues in Accounting Education*, *15*, 413-458.

Cannon, H. M., Cannon, J. N., & Andrews, C. (2010). Modeling cascading demand: Accounting for the effects of captive consumer relationships. *Developments in Business Simulation and Experiential Learning*, *37*, 33-41. (Reprinted in *The Bernie Keys Library*, available at http://www.absel.org)

Cannon, H. M., & Schwaiger, M. (2005). An algorithm for incorporating company reputation into business simulations: Variations on the Gold standard. *Simulation & Gaming*, *36*, 188-202.

Cannon, J. N., & Cannon, H. M. (2008). Modeling strategic opportunities in product-mix strategy: A customer versus product-orientation perspective. *Developments in Business Simulation and Experiential Learning*, *35*, 183-190. (Reprinted in *The Bernie Keys Library*, available at http://www.absel.org)

Cannon, J. N., Cannon, H. M., & Schwaiger, M. (2012). Modeling the "Profitable Product Death Spiral": Accounting for strategic product-mix interactions in marketing simulation games. *Simulation & Gaming*, *43*, 761-777.

Chakravorty, S. S., & Verhoeven, P. R. (1996). Learning the theory of constraints with a simulation game. *Simulation & Gaming*, *27*, 223-237.

Draman, R. H., Lockamy, A. III, & Cox, J. F. III. (2002). Constraint-based accounting and its impact on organizational performance: A simulation of four common business strategies. *Integrated Manufacturing Systems*, *13*, 190-200.

Gold, S. (2005). System-dynamics-based modeling of business simulation algorithms. *Simulation & Gaming*, *36*, 203-218.

Goldratt, E. M., & Cox, J. (1992). *The goal: A process of ongoing improvement* (2nd rev. ed.). New York, NY: North River Press.

Gomory, R. (1963). An algorithm for integer solutions to linear programs. In R. L. Graves & P. Wolfe (Eds.), *Recent advances in mathematical programming* (269-302). New York, NY: McGraw-Hill.

Gomory, R. (1965). On the relation between integer and noninteger solutions to linear programs. *Proceedings of the National Academy of Sciences*, *53*, 260-265.

Hilmola, O. (2001). Theory of constraints and outsourcing decisions. *International Journal of Manufacturing Technology and Management*, *3*, 517-527.

Johnson, R. M. (1971). Market segmentation: A strategic management tool. *Journal of Marketing Research*, *8*, 13-18.

Jordan, D. A. (2006). Supply-side modeling in a total enterprise simulation. *Developments in Business Simulation and Experiential Learning*, *33*, 345-347. (Reprinted in *The Bernie Keys Library*, available at http://www.absel.org)

Kee, R., & Schmidt, C. (2000). A comparative analysis of utilizing activity-based costing and the theory of constraints for making product-mix decisions. *International Journal of Production Economics*, *63*, 1-17.

Koksal, G. (2004). Selecting quality improvement projects and product mix together in manufacturing: An improvement of a theory of constraints-based approach by incorporating quality loss. *International Journal of Production Research*, *42*, 5009-5029.

Kotler, P., & Keller, K. (2012). *Marketing management* (14th ed.). Englewood Cliffs, NJ: Prentice Hall.

Lea, B., & Fredendall, L. D. (2002). The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance. *International Journal of Production Economics*, *79*, 279-299.

Low, J. T. (1992). Do we really need product costs? The theory of constraints alternative. *Corporate Controller*, *5*, 26-36.

Manne, A. S. (1960a). Comments on "interindustry economics." *Naval Research Logistics Quarterly*, *7*, 385-391.

Manne, A. S. (1960b). Linear programming and sequential decisions. *Management Science*, *6*, 259-267.

Manne, A. S. (1960c). On the job-shop scheduling problem. *Operations Research*, *8*, 219-223.

Mukherjee, A., & Wheatley, W. J. (1999). The ABC's of teaching the theory of constraints to undergraduate business students. *Developments in Business Simulation and Experiential Learning*, *26*, 274-279. (Reprinted in *The Bernie Keys Library*, available at http://www.absel.org)

Patterson, M. C. (1992). The product-mix decision: A comparison of theory of constraints and labor-based management accounting. *Production & Inventory Management Journal*, *33*(3), 80-85.

Rust, R. T., Zeithaml, V. A., & Lemon, K. N. (2000). *Driving customer equity: How customer lifetime value is reshaping corporate strategy*. New York, NY: The Free Press.

Shapiro, B. P. (1991). Product line planning. In R. Dolan (Ed.), *Strategic marketing management* (208-219). Cambridge, MA: Harvard Business School Press.

Sheu, C., Chen, M., & Kovar, S. (2003). Integrating ABC and TOC for better manufacturing decision making. *Integrated Manufacturing Systems*, *14*, 433-442.

Spoede, C., Henke, E. O., & Umble, M. (1994). Using activity analysis to locate profitability drivers. *Management Accounting*, *75*(11), 43-48.

Taylor, L. J., III, Jackson, M. J., Jackson, W. T., & Seanard, E. (2007). Goldratt's thinking process: Is there a place for it in the total enterprise simulation. *Developments in Business Simulation and Experiential Learning*, *34*, 379-386. (Reprinted in *The Bernie Keys Library*, available at http://www.absel.org)

Teach, R. D. (1984). Using spatial relationships to estimate demand in business simulations. *Developments in Simulation and Experience Learning*, *11*, 244-246. (Reprinted in *The Bernie Keys Library*, available from http://absel.org)

Teach, R. D. (1990). Demand equations for business simulations with market segments. *Simulation & Gaming*, *21*, 423-442.

Teach, R. D. (2008). Demand equations which include product attributes. *Developments in Business Simulation and Experiential Learning*, *35*, 161-166. (Reprinted in *The Bernie Keys Library*, available at http://www.absel.org)

Tsai, W., Lai, C., Tseng, L., & Chou, W. (2008). Embedding management discretionary power into an ABC model for a joint products mix decision. *International Journal of Production Economics*, *115*, 210-220.

Yahya-Zadeh, M. (1998). Product-mix decisions under activity-based costing with resource constraints and non-proportional activity costs. *Journal of Applied Business Research*, *14*(4), 39-46.

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