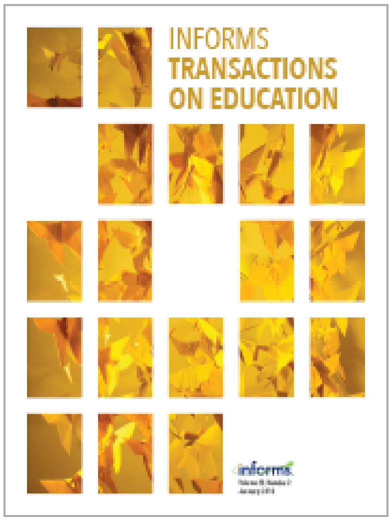

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The Building Blocks of Supply Chain Management

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Abstract

Supply chain management is one of the most complex business disciplines, comprising activities and interactions within and between many of the traditional functional areas of a firm and their channel partners. No longer can a company place its entire focus on its own operations because long-term success is becoming increasingly dependent on actions and decisions of upstream and downstream firms in the supply chain. Organizations that effectively collaborate with their supply chain partners position themselves for success in 21st-century markets. In order to prepare our students to make decisions in this complex environment, educators in operations research and management science must introduce students to the important interactions which are essential to effective supply chain management.

We have developed a classroom supply chain simulation incorporating Lego™ bricks to highlight the flow of materials, products, and information through the channel. Students assume the responsibilities of various supply chain functions and must work together to provide finished products according to a production schedule and a rush customer order. The exercise was designed for an undergraduate introductory course in supply chain management, transportation and logistics, or management science in a business or industrial engineering school. It reinforces lectures and discussions about the different functional areas of the supply chain and serves to energize students about the remainder of their curriculum in the field. The follow-up assignments included with the simulation allow students to execute the major steps of the production planning process within the familiar context of the company used in the simulation exercise.

1. Supply Chain Simulations

Classroom simulations have been the hallmark of experiential supply chain education since the invention of the Beer Game at MIT in the 1960s. This well-known simulation emphasizes the information distortion promulgated by a multi-echelon supply chain with decentralized decision making and no forecast sharing. Students typically discover that total supply chain inventory and backorder costs reduce when the different echelons collaborate by sharing end-user demand information. The Beer Game began as a board game where students passed cards between the channel levels to represent orders and inventory movements, and many instructors still implement the game in their classes in this manual form. The game has recently been computerized and made available online [(1)] and on the companion CD-ROM in Simchi-Levi et al. (2003). Coakley et al. (1998) discuss the advantages and disadvantages of a computerized implementation of the Beer Game compared to the manual version.

The Beer Game has undoubtedly undergone countless modifications and extensions over the past four decades. One published example of such an extension is given in Sparling (2002). In this version of the game, students are given the opportunity to build collaborative forecasting models after an initial run of the game

(1) http://beergame.mit.edu/

illustrated a large amount of information distortion. The students then play the Beer Game a second time using these models to determine the value of collaboration (and, therefore, information). Chen and Samroengraja (2000) detail a similar version of the Beer Game where the consumer demand distribution is independent and identically distributed for all periods and is known by all echelons of the supply chain. Anderson and Morrice (2000) describe an extension of the Beer Game to a service-oriented firm (a mortgage lender). In this context the echelons of the supply chain are the different processing stations involved in approving a mortgage application. Instead of placing orders at each time interval, the echelons adjust the workforce based on the queue lengths at each station.

Educators have developed other simulations to illustrate more-specific supply chain concepts. The companion CD-ROM in Simchi-Levi et al (2003) also contains a program entitled "The Risk Pooling Game," which examines the service-level benefits of consolidating inventory at a distribution center instead of at each individual retail location. Sun (1998) develops a production game that illustrates the differences between the Material Requirements Planning (MRP) and Just-in-Time (JIT) systems of production control using playing cards and manual documentation. Pendegraft (1997) uses Lego™-based products to illustrate the pivoting and shadow price concepts in linear programming, and Myers (2002) details a computerized version of Pendegraft's activity. ten Wolde (2000) discusses a three-day executive management program using Lego™ bricks, which allows the students to assume different responsibilities in the organization to gain insight into the different positions. Weiss (2003) details another Lego™-based activity which focuses on quality improvement by allowing students to engage in product and process redesign to improve efficiency.

All of these activities have been undeniably successful in various classroom environments, but they each focus on one specific process or concept within the supply chain. Even the Beer Game, which is often used as an introductory supply chain exercise, emphasizes the effect of information distortion in the performance of a serial supply chain. None of these activities provides a general introduction to the forward and reverse flows of materials, goods, and information throughout the supply chain. In response to this educational need, we have developed the MHI classroom simulation and follow-up analytical assignments. Our classroom exercise is designed as a general introduction to the field of supply chain management and the roles of the vast number of functional areas comprised therein.

The remainder of this paper is organized as follows. The next section provides a brief overview of the MHI activity. Section 3 discusses the objectives and pedagogical goals we had in designing the exercise, and Section 4 provides our recommendations for the various ways in which instructors could utilize the activity in their courses. We offer some of our classroom experiences and summarize our discussion in the final two sections.

2. Activity Overview

2.1. The MHI Classroom Exercise

The classroom exercise simulates seven days of the supply chain operations of an equipment manufacturer, Material Handling Incorporated (MHI); a 3rd-party logistics provider, Pretty Darn Fast (PDF); and an equipment integrator customer, Equipment USA-using Lego™ bricks to build the products. MHI sells its units through a direct channel as well as through value-adding equipment integrators who specify MHI's products for their customers. Groups of students each assume the role of one of the functional areas of MHI's supply chain and must perform the requisite tasks to execute an established production schedule.

The MHI exercise is designed for eight groups; the recommended number of students assigned to each functional area varies with respect to the area's responsibilities. Most of the groups should have between three and six students; complete details and suggested modifications for smaller classes are provided in the attached teaching notes. MHI has three manufacturing plants in Cleveland, Cincinnati, and Pittsburgh; each of these plants specializes in the production of a specific type of material handling equipment component. The plants ship their components to the Columbus, OH, distribution center (DC), which assembles them into final units before shipping them to the customer. (See Figure 1 for an example of the assembled final product.) The Columbus DC also functions as a raw material warehouse that fills material orders from the plants. All shipments of goods and materials are accomplished via the third-party logistics provider, and MHI's ERP system handles all communications between departments. (Two groups of students assume these respective roles during the simulation.) MHI's customer base is represented by one equipment integrator, Equipment USA, which places orders with MHI's customer service and order management (CS/OM) department. (Again, two groups of students take on these respective roles during the simulation.) During the course of the exercise, Equipment USA requests status reports from the CS/OM department about its orders. The CS/OM department contacts the plants and the Columbus DC to determine whether the orders are expected to be delivered on time and communicates this information back to Equipment USA.

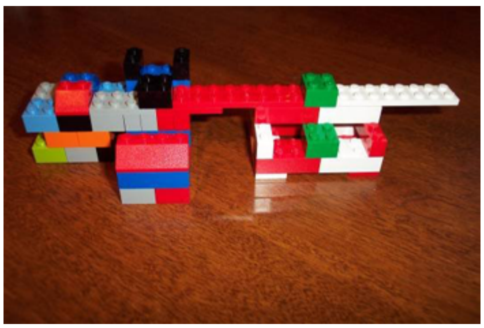

Figure 1: Example of an assembled final product (RGW Total Packaging System)

The activity begins with a production schedule for make-to-stock units that are due at the warehouse on Day 3 and Day 5. During the course of the simulation, MHI's CS/OM department receives a custom order from Equipment USA that is requested for delivery on Day 6. These units are modified versions of MHI's make-to-stock units to ensure compatibility with Equipment USA's existing material handling systems. The CS/OM department has the customized bills of materials and assembly drawings for these modified units; this group must disseminate these modifications to the manufacturing plants and the DC along with the information about the order quantities and deadlines. The challenge of the simulation is that MHI's supply chain must react to this important expedited custom order to satisfy its customer's requirements. Students are required to make decisions regarding the scheduling of customized unit production, the time frame for ordering components to satisfy both the stock and customized orders, and the required actions to coordinate the successful and timely delivery of the customized units.

2.2. Follow-Up Analytical Assignments

The MHI classroom simulation requires students to execute a previously-formulated production plan to emphasize the complexity and importance of the interactions between many diverse functional areas within a firm and between firms that must be managed in an effective supply chain. In order for instructors to draw and build upon the experiential foundation of the simulation exercise throughout the semester, we have also developed a series of follow-up analytical assignments that charges students with performing the steps of the production planning process-demand forecasting, aggregate production planning, and material requirements planning-within the context of MHI's business environment. After executing MHI's production plan in the classroom simulation, these assignments provide students with the opportunity to engage in the hierarchical planning process that was required to establish the type of plan given in the simulation exercise. They also establish the linkage between a firm's planning decisions and the execution of those planned activities.

All of these analytical assignments are self-contained regarding the data needed to answer the questions; therefore, instructors can utilize any or all of these assignments according to the specific topics that they cover in their courses. The benefit of using all of the assignments, though, is that this emphasizes the dependency of these particular planning activities on each other. Specifically, the demand forecast generated is an input to the aggregate production planning problem, and a weekly version of the production plan is an input to the material requirements planning exercise. The demand forecasting assignment charges students to evaluate several forecasting models and select one with which they can produce a monthly forecast for MHI's base product, the Total Packaging System, for the upcoming year. The aggregate production planning and material requirements planning assignments take that forecast for the assembled system and focus on the decisions that must be made at the Pittsburgh plant in order to produce its specialized component, the YW800 RFID and Bar Code Scanner, to satisfy the forecasted end-unit demand.

The adoption of these analytical assignments maintains the continuity of the course and extends the impact of the MHI simulation exercise throughout the semester. When they are completing the assignments that are set in the same business environment as the classroom simulation, students have an experiential point of reference to anticipate the effects of the decisions that they are currently making on the execution of supply chain operations like the ones they performed in the simulation. Instructors who teach the topics of demand forecasting, aggregate planning, and material requirements planning would likely assign homework exercises of difficulty and complexity similar to the ones we have created. By replacing other assignments with these, instructors can assess the students' understanding of the analytical procedures required to solve the problems as well as realize the benefits of maintaining the continuity of the MHI business environment throughout the entire course.

2.3. Case Materials[(2)]

We have included the following files as attachments for instructors' use:

1. MHI Case Introduction
2. MHI Teaching Notes
3. MHI Group Instructions
4. MHI Forms Excel File (includes Bill of Lading, Material Order Form, Purchase Order, Internal Product Requisition, and Customer Order Notification)
5. MHI Introduction PowerPoint Slides
6. MHI Bills of Material and Assembly Instructions PowerPoint File (See Figures 2 and 3 for examples of these documents.)
7. MHI Mail Slips
8. MHI Name Tents
9. MHI Follow-Up Analytical Assignments and Solution Files
10. MHI Aggregate Production Plan Mosel Code (for use with Dash Optimization's XpressMP Software)

We designed the products to be built in this activity around a basic set of Lego™ bricks (#4496 Fun with Building Tub) that is available at any toy store or discount retailer for approximately $19.99. The only additional products that instructors must purchase are some sort of containers to facilitate transportation of materials between the groups. We recommend using disposable plastic containers with lids to store the plants' and the DC's beginning inventories of materials and plastic bags for transportation during the simulation. The teaching notes contain a detailed discussion about the setup that is required for the activity including suggestions of the quantities of each form to prepare.

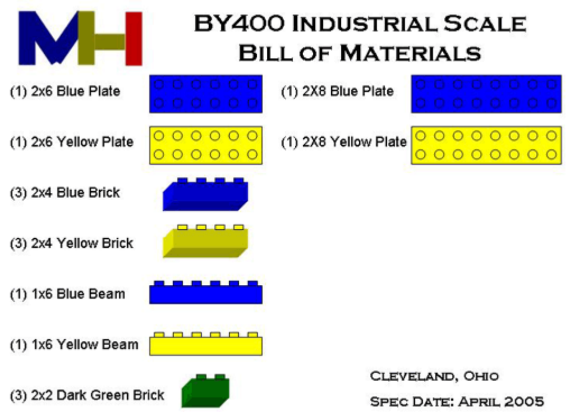

Figure 2: Example of a bill of material provided in the MHI activity

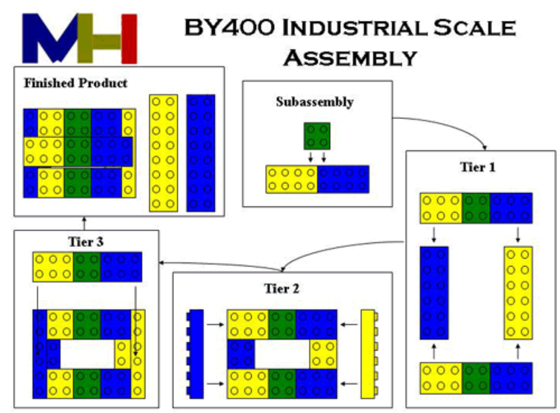

Figure 3: Example of the assembly instructions provided in the MHI activity

3. Objectives and Pedagogical Goals

The main objective of the classroom simulation is to expose students to the challenges of managing a supply chain and to emphasize the responsibilities of each functional area and intermediary. Students assume the identity and responsibilities of one of MHI's supply chain departments, which enables them to experience the dependency of each department on the work of others to meet the customers' demands. This impresses

(2) http://ite.pubs.informs.org/Vol6No3/DrakeMawhinney/SCMBuildingBlocks.zip

in their minds the complexity of managing a supply chain due to the level of coordination that is required between the functional areas and the requirement that a supply chain be flexible and responsive to change. The simulation also demonstrates that customer satisfaction is the most important metric for overall supply chain performance. World-class supply chains concentrate their efforts on improving the whole system rather than making one process more efficient.

Many of the functional areas of a company that characterize supply chain management (manufacturing, warehousing, customer service, etc.) have been cost centers for companies in the past. Over the past decade supply chain researchers and practitioners have mitigated the negative financial impact of these disciplines by building value-creating processes into their operations. The MHI classroom simulation highlights several of these value-added functions within the supply chain. The Customer Service / Order Management department acts as a conduit that facilitates communication between the customer and the firm's manufacturing and distribution operations. It is also responsible for transmitting customized product specifications and translating a custom order into internal component requirements for the associated manufacturing plants and distribution center. The importance of customer service is often underappreciated in supply chain management curricula. The distribution center adds value to MHI's product by assembling components into finished units before shipping, which allows the plants to specialize in the production of only a few different types of components instead of producing the entire unit.

Like many business disciplines, supply chain management has a language and a set of procedures all its own. Immersion in this terminology can be a difficult experience for new students in the field. Our exercise employs some of the most important transaction facilitators in supply chain operations (bills of lading, bills of material, purchase orders, and internal requisitions) and requires students to use the new terminology (such as "consignee," "third party logistics provider," "intermediary," and "visibility") within the context of supply chain operations. The learning process associated with the incorporation of the terms and concepts adds to the complexity of the exercise for students who are being introduced to supply chain management by requiring them to understand and apply the new material quickly.

To maximize the cognitive benefit of including the MHI classroom simulation in the supply chain curriculum, we designed the activity in accordance with several educational best instructional practices: simulation, advance organizers, the ill-defined task, and problem-based learning. Simulations provide students the opportunity to actively apply skills and knowledge in a competitive environment of achieving a goal (McKeachie, 2002). One of the challenges in the MHI exercise is for each group to perform well, but the exercise is only successful if all groups perform well. The business process diagram (see Figure 4) used to explain the flow of the exercise is an example of an advance organizer, first introduced by Ausubel (1963). The advance organizer reinforces the students' personal experiences and academic studies related to supply chain management. When the students first view the tasks required by the activity, they may view it as an impossible proposition due to the lack of specific definition. The small group environment provides the social reinforcement necessary to discourage students from quitting and helps them focus on accomplishing their small role in the fulfillment process (Huba and Freed, 2000). The students must apply multiple concepts from their prior experiences to address the requirements they deduce from the responsibilities assigned to them in order to solve the problem (Macfarlane and Ottewill, 2001). Educational research has found that this form of problem-based learning improves retention of concepts and improves students' attitudes about their studies (Zappe, 2004).

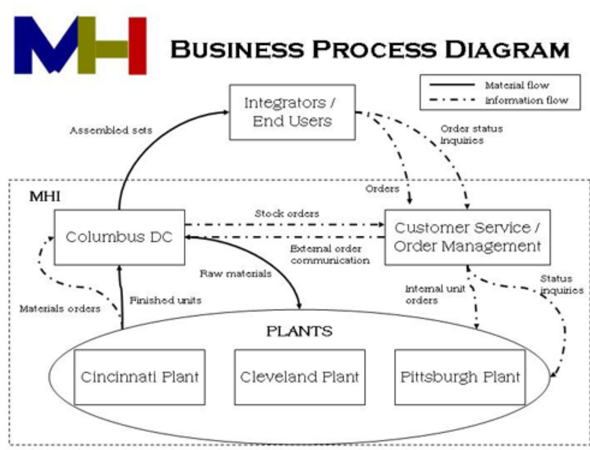

Figure 4: The business process diagram used to explain the flow of materials and information through MHI's supply chain

4. Suggested Use

The MHI simulation highlights the interactions and conflicting objectives of various functional areas within the supply chain. We designed the activity for new students of supply chain management regardless of the educational level. The most natural home for the simulation is in an undergraduate introductory course in supply chain management, transportation and logistics, or operations management. Students who have had some exposure to general supply chain topics but have not studied specific functions in depth stand to gain the most from the exercise, because it provides them with first-hand experience of the functions, tasks, and responsibilities that they have learned about in lectures or through readings. This provides reinforcement and aids students' retention of earlier material presented in the course. The MHI exercise would also be appropriate in a general business or engineering survey course to reinforce an introductory discussion of supply chain management. It could also be a useful tool in executive education programs for professionals in other business disciplines, such as accounting or information systems, to enhance their understanding of the difficulty of managing the various flows necessary to execute supply chain processes efficiently.

Within a particular course the MHI classroom simulation and analytical assignments could be used in a variety of different sequences, each of which has its particular merits. (See Anderson and Lawton (2003) for recommendations on the timing of utilizing business simulations within a course.) One possible sequence is to use the classroom simulation towards the beginning of the semester as an introductory activity and then assign the analytical activities later in the semester when each of the particular parts of the production planning process is covered in the course. (This is the order we envisioned, which should be evident from the fact that the analytical assignments are denoted as "follow-up" to the simulation activity.) The exercise does not require the students to read any preparatory material *per se*(other than the case introduction document), but instructors should only use the exercise after giving, at minimum, a general introduction to the flows, operations, and interactions involved in the supply chain. We have included several slides in the introductory PowerPoint presentation that define any new terminology that is important to completing the exercise. Students may also find it helpful to read the introductory chapter of a basic supply chain management text such as Chopra and Meindl (2007), Ballou (2004), or Coyle et al. (2003) in advance of the simulation. By conducting the MHI exercise early in the course, the students get experiential exposure to the supply chain flows and interactions early on, and the simulation experience is reinforced by each of the production planning assignments.

Other instructors may choose to swap the sequence, though, and this order of presentation has also been effective. By performing the classroom simulation at the end of the semester, students can synthesize the production planning assignments they completed earlier and complete the natural progression from planning activities to the operational execution of the plan. One student who performed the simulation in two classes-one time at the beginning of the semester and the other time towards the end of the course-remarked that many of the concepts presented throughout the course were solidified and clarified by conducting the exercise at the end of the semester. If instructors choose this sequence of activities, we recommend that they require the students to read the MHI Case Introduction document before having them complete any of the analytical assignments to establish familiarity with the MHI company and its business processes.

Each day of the simulation exercise lasts for seven minutes, so the entire activity requires 49 minutes of class time. (This could be reduced to five or six minutes under time constraints, but our experiences in compressed time sessions have confirmed that the ideal time is seven minutes per day.) Consequently, the simulation would fit into a 50-minute class session, although that would not leave any time for an introduction or a wrap-up discussion in that same period. We have mainly used the activity in a 90-minute session, allowing for a 15- to 20-minute introduction to the rules and the flow of the game (using the introductory PowerPoint slides provided) and an equal period of time for a synthesizing wrap-up. Instructors should take note of interesting student comments throughout the exercise, especially those that raise important supply chain management issues, so that they can discuss them in the wrap-up.

The students should already be in their groups and have their departmental identities before the discussion of the rules so that they can concentrate on their specific tasks during the business process walk-through. Even before the discussion of the rules, the students should read the case introduction so that they understand the type of products MHI manufactures. We have made the reading of this introduction a homework assignment to be accomplished before class, but other instructors could assign the students to read it in class before the simulation starts if time allows.

Due to the number of potential decisions that each of the eight groups can make, the outcomes of the classroom simulation and the path leading to those outcomes can vary significantly from class to class. The instructor may find it helpful to prepare "house rules" regarding the ability of students to improvise from the specified activities. Students will often ask for permission to collaborate or help a location that may be overrun with tasks at a given time. These are frequent practices in the business world and can be used as opportunities to emphasize the value of eliminating the barriers between members of the supply chain. At the same time, preventing such interaction would provide a lesson of the frustration that exists when supply chain partners do not support each other.

5. Classroom Results

We have used the MHI classroom simulation (and an earlier version) for several years in an undergraduate business course entitled "Introduction to Supply Chain Management." We also enacted it in an introductory undergraduate industrial engineering course on modeling and an upper-level undergraduate course on supply chain modeling. The most obvious observation we have made is that each class of students, without exception, has been energized by the activity. Part of this enthusiasm, no doubt, stems from the replacement of a traditional lecture session with an interactive game, but the majority of it is unmistakably genuine interest in accomplishing the tasks at hand as well as they can. Conversations with groups of students during some down times for their group have included questions about how their tasks are really accomplished in business environments, identification of bottlenecks caused by other groups' activities and responsibilities, and strategies for meeting their objectives when work comes to them through the channel.

While not all, many classes have been able to produce the four final units required by the end of the simulation, but only one of them has met the Day 6 deadline for the custom order. We have used this result to highlight the fact that some groups performed their tasks well did not matter because the customer did not receive her order on time. Work at the distribution center tends to pile up in the middle portion of time because all of the plants are ordering parts concurrently to manufacture components for the rush order. Sometimes one unit is ready on Day 6 (instead of the required two), and we instruct the CS/OM department to contact the customer to see if she will accept a partial shipment. Just as in each day of a supply chain's operations, each trial of the simulation has generated unique business circumstances such as damaged freight, inaccurate inventory systems, incomplete raw material orders, and inefficient manufacturing operations that instructors can emphasize in the post-activity discussion. This gives students a sense of some of the real problems that can arise in supply chains and their potential causes.

It is important to remember that failure to complete the task of building all four required units on time does not equate to failure of learning from the exercise. The wrap-up discussion provides an opportunity to discuss the factors that lead to the results achieved by the students regardless of the number of Lego™ units completed. Supply chains do not always work perfectly, and students can take away understanding of the strengths and weaknesses of their processes whether they complete zero or all four units.

The MHI classroom simulation is fast paced and can take a variety of different directions depending on the actions of each of the eight functional groups. Students generally become comfortable with their function's roles quickly in providing the stock components, but they are often challenged when the custom order is introduced. In addition, the errors described above, while simulating real-world problems, often elicit emotional responses by the members of other functional groups. All of these reactions provide an opportunity to draw a comparison between the exercise and practical supply chains. Instructors will find the conversations between groups via the email communication slips to be a great source of material to review in the wrap-up. Discussions regarding the reasons for delays, the lack of response to requests for information, and the limited ability to communicate with the customer are examples of previously-encountered concerns expressed by students that can be reflected upon during a review of the exercise results.

Student feedback about the MHI activity has been very positive. They welcome the hands-on approach as a change from the ordinary lecture-based classroom environment. Comments have emphasized that the exercise has helped them to gain a more complete picture of how a supply chain works and why it can be so difficult to manage. ("I learned how complex the supply chain is and how everything must work together seamlessly (no mistakes) in order to fill orders and satisfy the customer.") Most importantly, though, the MHI classroom simulation seems to increase their awareness of and enthusiasm about the field of supply chain management and propels them forward in their curriculum. ("This was fun! Harder than I thought! We all need good communications to work it out.")

6. Future Opportunities

This tangible classroom simulation provides a brief introduction to the real world of supply chain operations as the game emulates transactions and processes for a discrete segment of time and set of products. In part, the experiential learning associated with the exercise comes from the pressure to coordinate multiple parties' actions in order to accomplish the specified tasks in the time allotted. The use of bills of material and assembly instructions emulates the task of translating graphic representations of products to the actual finished good. The challenge of properly assembling and safely moving the subassemblies and final products requires attention to details and teamwork.

While designed to be effective for a single class session, the MHI activity could be expanded by developing a computer simulation that incorporates the foundational concepts of the current MHI simulation. The benefit of physically assembling a product could still be supported by software to simulate the information exchange and management; however, graphics could be developed to emulate the individual components and their assembly which would change the skills required from physical dexterity to computer skills. This transition would change the focus of the game, but it would also permit extending the simulation to run across multiple classes and include more realistic products with a larger number of parts and more extensive inventories.

Much like the transition of the Beer Game from a board game to a computer simulation, MHI could be programmed to simulate the tangible version of the exercise as in Coakley et al. (1998). The computer simulation would also provide an opportunity to include more complex issues associated with supply chain operations. There is a risk that the addition of too many factors will make the simulation too complex; and rather than contribute to student supply chain self-efficacy, it would be confusing and a detriment to student learning (Cannon, 1995). In the manual activity any delays are caused by decisions and actions made by humans, just as in business, and not according to some probability distribution. Students experience frustration with their classmates similar to that between employees within different portions of the supply chain. This experience of the difficulty with trying to coordinate human actions may be difficult to incorporate into a comuputerized exercise. However, a computer simulation designed with these risks in mind could enhance the scope of the current MHI activity, providing a more robust exercise while reducing the learning curve associated with mastering the simulation (Coakley et al., 1998).

Since the practical task of managing a supply chain is extremely complex, the need and benefit of a comprehensive, integrated, and collaborative supply chain simulation for educational and training environments is very real. Incorporating more advanced decision concepts related to forecasting, planning and scheduling, inventory management, etc. would require technology support to maintain control and manage complexity. A game of this degree would require a large investment of time from students and instructors to learn and master the gameplay. With requiring a minimal amount of class time, the MHI exercise addresses a small segment of supply chain operations in an attempt to give students a glimpse into the issues of day-to-day operations.

7. Summary

We educators in the field of supply chain management are at a decided disadvantage when compared to our colleagues in more traditional business disciplines such as accounting, finance, or marketing. Incoming college freshmen have a pretty clear understanding about what these more-traditional concentrations are all about, but it is highly possible that they have never heard of supply chain management. Thus, often our responsibilities as educators become expanded to marketing the profession as well. Simulations such as our MHI exercise reinforce the concepts covered in introductory courses while at the same time generate excitement and enthusiasm about the field of study as a whole. This makes a student more likely to take more focused courses that cover specific topics in greater detail and utilize other excellent, preexisting classroom simulations such as the Beer Game that concentrate on these particular supply chain concepts.

8. Acknowledgments

We would like to recognize the work of Rebecca Krull on a previous version of the classroom simulation exercise and Paul Griffin for his accommodation in using this activity in his Spring 2005 course. This paper and the classroom tools described herein benefited greatly from the comments and suggestions of the editors and three anonymous referees.

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