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ANALYZING EMERGENT BEHAVIOR OF SUPPLY CHAINS FOR PERSONAL PROTECTIVE EQUIPMENT IN RESPONSE TO COVID-19

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THESIS

ANALYZING EMERGENT BEHAVIOR OF SUPPLY CHAINS FOR PERSONAL PROTECTIVE EQUIPMENT IN RESPONSE TO COVID-19

by

Joshua P. Beaver

September 2021

Thesis Advisor: Kristin M. Giammarco
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The novel coronavirus (COVID-19) revealed weaknesses in supply chains of companies that produce personal protective equipment (PPE), resulting in nationwide shortages. A government-industry collaborative platform between the National Institute for Standards and Technology (NIST) and Helpful Engineering is under development to act as an exchange for material and equipment at each level of the supply chain. The intent of this is to create an online agile production platform (APP) for PPE. There is a need to proactively limit negative interactions with the APP. The creators of the APP constrain bad behavior or abuse of the system using a "bottom up" approach of coding requirements. In tandem, a "top down" approach of the system is modeled using Monterey Phoenix, a behavioral modeling platform. Stakeholders and processes are modeled to show different permutations of interactions. Impossible scenarios are removed with model constraints. The remaining traces are analyzed for emergent behavior and compared with the constraints programmed into the model. Findings of this research include unexpected emergent behavior in two scenarios. One scenario explored delivered quality to the customer, and analysis exposed a gap that allowed counterfeit parts into the APP. The other scenario explored how the APP managed the supply chain. Weaknesses that allowed missed inspections to pass bad parts were also found. The models developed will drive changes that increase confidence in the APP.

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ANALYZING EMERGENT BEHAVIOR OF SUPPLY CHAINS FOR PERSONAL PROTECTIVE EQUIPMENT IN RESPONSE TO COVID-19

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ABSTRACT

The novel coronavirus (COVID-19) revealed weaknesses in supply chains of companies that produce personal protective equipment (PPE), resulting in nationwide shortages. A government-industry collaborative platform between the National Institute for Standards and Technology (NIST) and Helpful Engineering is under development to act as an exchange for material and equipment at each level of the supply chain. The intent of this is to create an online agile production platform (APP) for PPE. There is a need to proactively limit negative interactions with the APP. The creators of the APP constrain bad behavior or abuse of the system using a "bottom up" approach of coding requirements. In tandem, a "top down" approach of the system is modeled using Monterey Phoenix, a behavioral modeling platform. Stakeholders and processes are modeled to show different permutations of interactions. Impossible scenarios are removed with model constraints. The remaining traces are analyzed for emergent behavior and compared with the constraints programmed into the model. Findings of this research include unexpected emergent behavior in two scenarios. One scenario explored delivered quality to the customer, and analysis exposed a gap that allowed counterfeit parts into the APP. The other scenario explored how the APP managed the supply chain. Weaknesses that allowed missed inspections to pass bad parts were also found. The models developed will drive changes that increase confidence in the APP.

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LIST OF ACRONYMS AND ABBREVIATIONS

APP	Agile Production Platform
CDC	Centers for Disease Control and Prevention
COVID-19	Coronavirus Disease 2019
DOD	Department of Defense
FAI	First Article Inspection
LSI	Lead Systems Integrator
MP	Monterey Phoenix
MRB	Material Review Board
MRP	Material Resource Planning
NIST	National Institute for Standards and Technology
NPS	Naval Postgraduate School
PPE	Personal Protective Equipment
QMS	Quality Management System
SCM	Supply Chain Management
SME	Subject Matter Expert
WHO	World Health Organization

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EXECUTIVE SUMMARY

This thesis investigates using Monterey Phoenix (MP) as a behavior modeling tool to find desired and undesired scenarios of personal protective equipment (PPE) supply chains within the agile production platform (APP), a marketplace that aspires to aggregate PPE systems and materials to preclude supply issues experienced during the COVID-19 pandemic.

To preclude the undesired events discovered in this thesis from becoming a reality and undermining the public's faith in the APP, requirements to minimize their probability of occurrence should be instituted. By requiring all suppliers to follow ISO 16678, an international standard of guidelines for counterfeit avoidance when dealing with interoperable commodities, the chance of counterfeit materials entering the APP are drastically reduced. A customer rating system could also be implemented to verify that the products received perform as expected.

A few steps are recommended for the other instance of emergent behavior that occurred within the APP's supply chain. A supplier rating system spanning the entire APP should be implemented like the customer rating system to measure on time delivery and quality. All suppliers should be expected to conform to the international standard ISO 9001, which establishes guidelines for a quality management system. Lastly, any nonconformance noted in a batch of part, regardless of how minute the producing company believes it to be, should be noted within the APP when it is ready for delivery. This way, the manufacturer of the next higher assembly can determine for themselves whether the defect could have any impact on the system.

To identify possible scenarios where supply chains have an undesired or unexpected outcome, realistic models of the supply chain interactions within the APP were constructed. MP executes code to create interactions between actors, actions, and activities by using constraints to guide the possibilities. By using this method, the permutations of interactions were analyzed between actors and the results of those interactions on output.

The first model composed was centered around delivered quality. Since this was the focus, traces are modeled by the different possibilities of interactions between a customer and the APP. More granularity was given to this model by challenging assumptions that the previous event guaranteed success for the following event. Each of these traces was approached as a "story" which walked through the process to see what plausible scenarios fit the outputs of the trace.

Emergent behavior is expected or unexpected and derived through analysis of the stories found within the MP model's traces. The expected emergent behavior found in this model was a disconnect between the customer, the APP, and the delivery service, resulting in a shipment that does not arrive as expected for a variety of reasons. Unexpected emergent behavior was also encountered, which manifested as a counterfeit part that made its way into the APP supply chain.

Next, a model was built to view the interrelations of supply chains with the APP as the intermediary. This modeled interactions among raw material suppliers, component suppliers, finished product suppliers, the customer, and the APP. Since the APP is connecting many supply chains that were disparate in the past, there are many more degrees of freedom within the system. This model was kept at a relatively generalized level, checking to make sure each phase of the supplier had the capacity, technical capability, and materials to produce the expected product.

Again, the team discovered both expected and unexpected emergent behavior in this model. The expected emergent behavior resolved as a component supplier that was still at maximum capacity despite the APP pooling more suppliers at all levels of production, which resulted in the order not being adequately fulfilled. The unexpected emergent behavior manifested as nonconforming material that still makes its way to the customer, either through a miscommunication or lack of inspection.

ACKNOWLEDGMENTS

There are multiple people I need to thank for helping me through my thesis research and composition. First, I'd like to thank Dr. Kristin Giammarco for helping me to find this topic and support me every step of the way through my research. Dr. Giammarco is a truly exceptional professor who brings her passion for systems engineering and Monterey Phoenix to every meeting, class, and study session. I would also like to think Dr. Wally Owen for his helpful insights and attention to detail as my second reader.

Next, I'd like to thank Dr. Edward Griffor from the National Institute for Standards and Technology (NIST) and the engineers at Helpful Engineering who provided feedback on my early models and assisted with bounding the problem and refining the solutions. The collaboration between government institutions, private industry and the Naval Postgraduate School was interesting and exciting. I feel I learned as much from the weekly meetings as I did when I refined the behavioral models for the team to review.

Third, I'd like to thank my cohort for all the support these past few years. It's truly amazing how close this degree program has made us, and I value the relationships this program has helped us build.

Lastly, and most importantly, I'd like to thank my wife Kristin Kauffman Beaver. Kristin convinced me to apply for this program and supported me through its entirety. When I had stressful classes or thesis deadlines, she always held our lives together by doing the things I no longer had time to do—and she did them with a smile. She is the reason for my success.

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I. INTRODUCTION

What happens when a global event destabilizes predictable and well understood manufacturing demand? Carefully crafted forecasts used to minimize production costs become the direct cause for empty store shelves. Further, what if the lack of capacity is directly tied to the loss of human life?

The global pandemic that gripped every country in late 2019 and throughout 2020 created a jarring new existence for humanity. Lean production systems that allowed businesses to keep costs low through processes such as just-in-time delivery were not properly positioned for the immense, global demand for personal protective equipment (PPE). Further, the tangled webs of supply chains created additional, unforeseen challenges to expedite orders of PPE. There was no easy way to see how much material or components each supplier had on hand at each level of the supply chain. The National Institute for Standards and Technology partnered with Helpful Engineering and the Naval Postgraduate School to develop a single marketplace supported by a new system known as the agile production program (APP) where material at all levels of the supply chain can be easily found.

This chapter details the initial problem statement, the background, challenges posed to the team and how success is measured. Chapter II examines past literature on supply chain planning and development, along with applications of Monterey Phoenix (MP) behavior modeling. Chapter III describes the methodology followed to build appropriate models for the APP. Chapter IV details the model scenarios and respective outcomes. Chapter V draws conclusions and makes recommendations for APP development.

A. BACKGROUND

The novel coronavirus, COVID-19, originated in Wuhan, China and quickly spread around the world. This virus can manifest in many ways, with those affected reporting symptoms that are mild or non-existent, to significant lung and other organ damage resulting in severe complications or even death (Centers for Disease Control and Prevention [CDC] 2020). COVID-19 is a highly transmissible virus spread mostly thru direct contact and aerosols from infected individuals (WHO

2020). This created an urgent need for PPE to reduce the spread, both for the public and health workers alike.

Supply chains were not adequately postured at the onset of this pandemic to meet the PPE needs of the world. Hospitals were forced to find ways to recycle PPE to avoid using and discarding their entire supply. The CDC released guidance to ration PPE, which can be found in Figure 1.

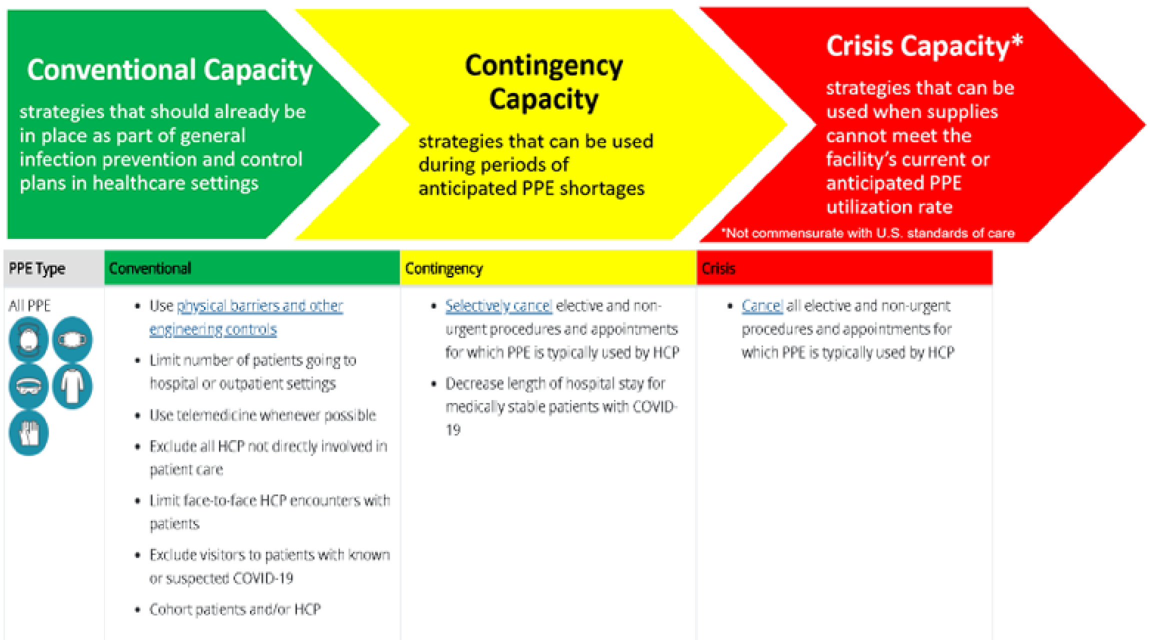

Figure 1. CDC Guidance on PPE Capacity Mitigation. Source: CDC (2020).

According to Benita Beamon, "A supply chain may be defined as an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials, (2) convert these raw materials into specified final products, and (3) deliver these final products to retailers" (Beamon 1998, 2). In the past, companies found efficiencies through vertical integration, where an enterprise owns all layers of an industry from raw material to the finished product (Harrigan 1985). In the present, companies compete globally, and optimizing special processes or assemblies for national or global distribution is seen as more agile and a way to increase profits while reducing overhead. Many manufacturing companies institute initiatives such as Total Quality Management (TQM) and Lean

Six Sigma (LSS), management styles that reduce waste and inventory, which can be costly (Naomi 2015).

B. STATEMENT OF THE PROBLEM

There may be unexpected outcomes from deploying the APP that have undesired or unintended consequences. The extent to which behavior modeling could be used to expose and preclude those events from negatively affecting the APP will be investigated.

C. RESEARCH OBJECTIVE

The APP is the solution under study for this thesis. The APP is a jointly developed marketplace by the National Institute for Standards and Technology (NIST) and private industry. This marketplace strives to connect disparate supply chains and weave them together to preclude supply chain disruptions such as the ones experienced early in the COVID-19 pandemic. The APP experiment explores if a system can be created that interfaces with all the important stakeholders in this supply chain to create a more seamless exchange of materials. An open sourced, accurate marketplace that connects the important suppliers may reduce the unknowns that currently are impacting the disparate supply chains.

A high-level concept of this interfacing exchange can be seen in Figure 2. This figure shows the raw data from stakeholders at the bottom that the APP would use on their platform to connect all levels of supply chains. The platform utilizes a 3rd party services to make sure transactions are secure, quality is vetted and the exchange is working as intended. This results in an interconnected web of suppliers that is much more resilient to small disruptions in sectors of the supply chain.

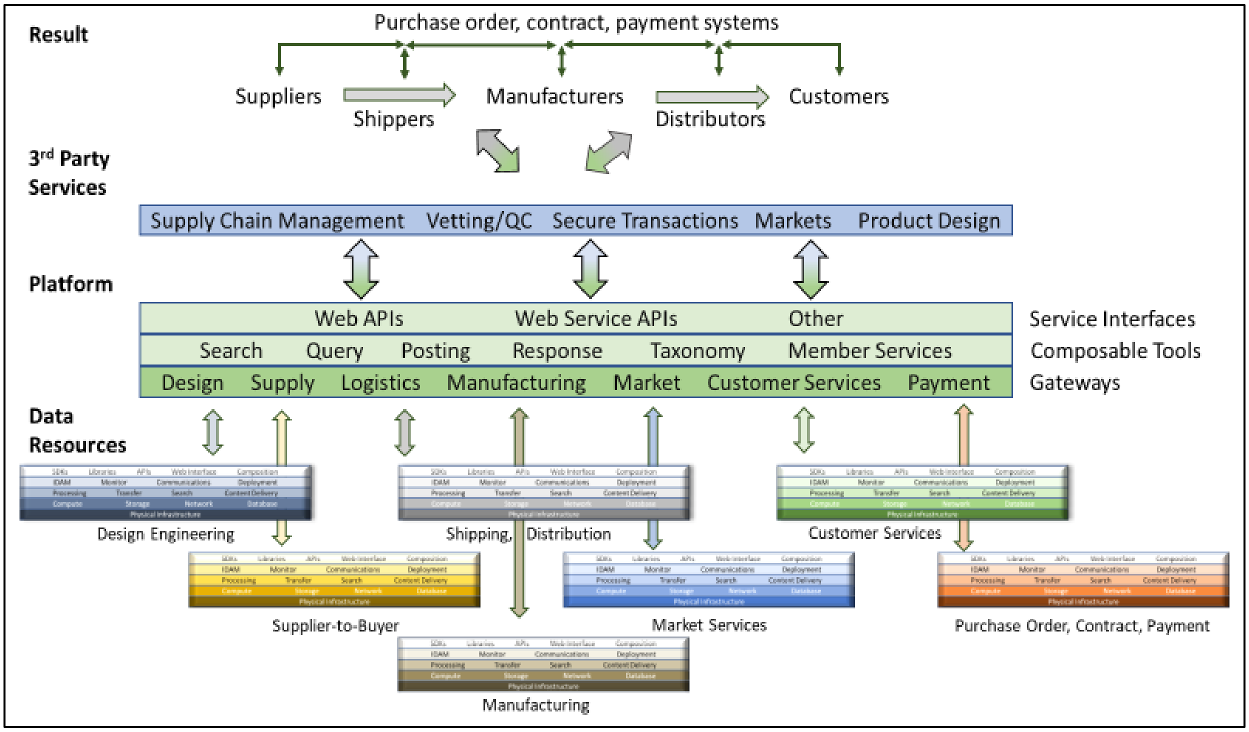

Figure 2. Agile Production Platform Concept. Source: Griffor (2020).

The APP development team has broad objectives beyond the scope of this thesis. These objectives assist in expressing the boundaries and overarching goals of the entire project. The first overarching goal of the APP must promote economic growth by enabling innovation in production and the emergence of new products, markets, and services through agile supply chain design, implementation, and management. The second goal of the broader team is to provide for resilience to disruption by enabling rapid supply chain assembly and adaptation, cross-sector and multi-provider sourcing, and adaptive repurposing of supply, production, and logistics capacity.

Specifically, the research goal of this thesis is to create common scenarios that may occur within the APP and try to find possible behavior that is unexpected or undesired. This allows the team to place requirements or restrictions in place proactively, rather than wait for the behavior to occur to actual suppliers or customers. The proactive nature allows for continuous improvement of the system without stakeholders having a negative interaction.

These scenarios involve different stakeholders and interactions to view the system from multiple perspectives. After the scenarios reach a realistic level of fidelity, they are recreated as a model using behavior modeling software. The results are inspected to identify any unexpected behaviors, both good and bad, that may result.

D. RESEARCH METHODOLOGY

This thesis utilizes an experimental research method. A literature review of MP applications in past research projects and deployment of software supply chain marketplaces was conducted first. The objective of this literature review is to bound the tool's limitations and understand its defining characteristics. This knowledge was then paired with personal experience of supply chains to create models and interpret them for this thesis. The research uses the MP behavioral modeling tool to explore and model different scenarios of interaction with the Agile Production Platform to probe for cases of previously unconsidered emergent behavior. MP produces scenarios in the form of event traces supporting an iterative inspection process to discover emergent behavior. Specifically, models are developed in Monterey Phoenix for scenarios or system attributes such as the supplier rating system within the APP. The findings will be shared with APP developers responsible for implementing controls to account for the discovered behavior. The MP scenario permutations reviewed are expected to include some behavior that is possible but not expected by the APP development team. APP developers can then validate and use MP scenarios to add constraints that nullify the emergent behavior. The model running and inspection repeats until no more unexpected emergent behavior is found in the Monterey Phoenix models.

E. SCOPE OF STUDY

The criteria for success of this study is defined as the identification, understanding, and control of emergent behavior in scenarios that can be reasonably expected within the APP. The mission of this study is defined as the development of several scenarios relevant to supply chain operations with requirements to reinforce positive outcomes or reduce the probability of negative outcomes. Measurement of this system is vital to measure its effectiveness, and those areas are defined in Table 1.

Table 1. Measures of the System

	Measurements Compared to Previous System	Qualitative Measurement
1.	PPE Deliveries to Critical Areas	More is Better
2.	Lead Times for Production of PPE	Less is Better
3.	Quality of PPE	More is Better
4.	Transmissibility of COVID-19	Less is Better
5.	Counterfeit or Inadequate PPE in use	Less is Better

F. ASSUMPTIONS ABOUT THE ENVIRONMENT

The following environmental conditions are considered as baseline requirements for this system:

Each data resource must stand on its own; no internal changes can be required to connect it to the platform and each resource retains control of its own business assets and processes.

The platform is participant-agnostic, enabling individuals and organizations of all sectors (e.g., suppliers, shippers, manufacturers, distributors, consumers, entrepreneurs, financers) and types (small, medium, large, women and minority-owned), to participate in peer-to-peer supply chain design, implementation, and/or management.

The platform is trustworthy, providing the foundation for trusted third party services such as secure transactions, trusted identity management, reliable participant vetting (including product and services quality information), and verifiable product certification and safety information.

There is no global control of platform operations. The platform system is open source and may be hosted by anyone.

The platform is general purpose in nature and not designed to support just one application. Examples of third-party applications include an offer/response market, intelligent search, status tracking, participant vetting, predictive planning services, and comparative options analyses including tradeoffs and conflicts for design space exploration.

G. BENEFITS OF STUDY

This study directly impacts the development of the APP, a system which acts as a marketplace for PPE suppliers. This effort is being coordinated by the NIST utilizing a private partnership with Helpful Engineering. NPS is assisting in a voluntary role to model and consult. When the APP is deployed, its goal is to increase production of all PPE to hospitals, individuals, and other organizations. The models developed make the platform more resilient towards malignant actors, increasing the confidence in the platform. Supply chains in general are utilized by the DOD, Navy and Systems engineering community in acquisition. Emergent behavior found during this research may also be applicable to other supply chain scenarios in acquisition.

H. SUMMARY

This thesis takes the framework of the APP introduced earlier in this section as a baseline for identifying possible supply chain threats. Chapter II details literature review of relevant topics, such as supply chain, quality management systems, and the behavioral modeling software Monterey Phoenix. Chapter III discusses the methodology of applying MP to supply chain scenarios, and introduces the syntax, grammar, and process of running traces. Chapter IV introduces different APP scenarios and their corresponding MP models. Also discussed here are the relevant traces from these models showing detection of emergent behaviors. Chapter V makes recommendations to control and correct the discovered emergent behaviors and offers future opportunities for other individuals interested in this research.

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II. LITERATURE REVIEW

This chapter details supply chain planning, supply chain development and supply chain management. It also describes the relevance of the MP behavioral modeling software, which is a tool for modeling and exploring emergent behavior in systems such as supply chains.

A. SUPPLY CHAIN PLANNING

According to Benita Beamon, a supply chain consists of materials flowing upward while information flows downward. A supply chain can consist of many levels, but generally speaks to the process of converting raw materials into components, converting those components into sub-assemblies, and finally integrating the sub-assemblies into a final product (Beamon 1998). Figure 3 depicts the core tenets that supply chains must follow to be successful. The overarching goal of a supply chain is to be competitive in the global market and provide a satisfactory product to the consumer. A group of companies need to have open communications and reliable logistics as a base to build upon. This leads to cooperation and a symbiotic relationship when properly executed (Stadtler 2004). However, supply chains are built on trust, which may not be guaranteed in the corporate world. Raw material and mid-level component manufacturers may have to deal with competing buyers of independent supply chains, or multiple components that take the same production line or resources. Product manufacturers must consider this reality at every level of their supply chain, because delivery of every single component is needed to finish the final assembly. Any hiccup could have a cascading effect that loses companies time and money waiting on parts to arrive (Stadtler and Kilger 2005).

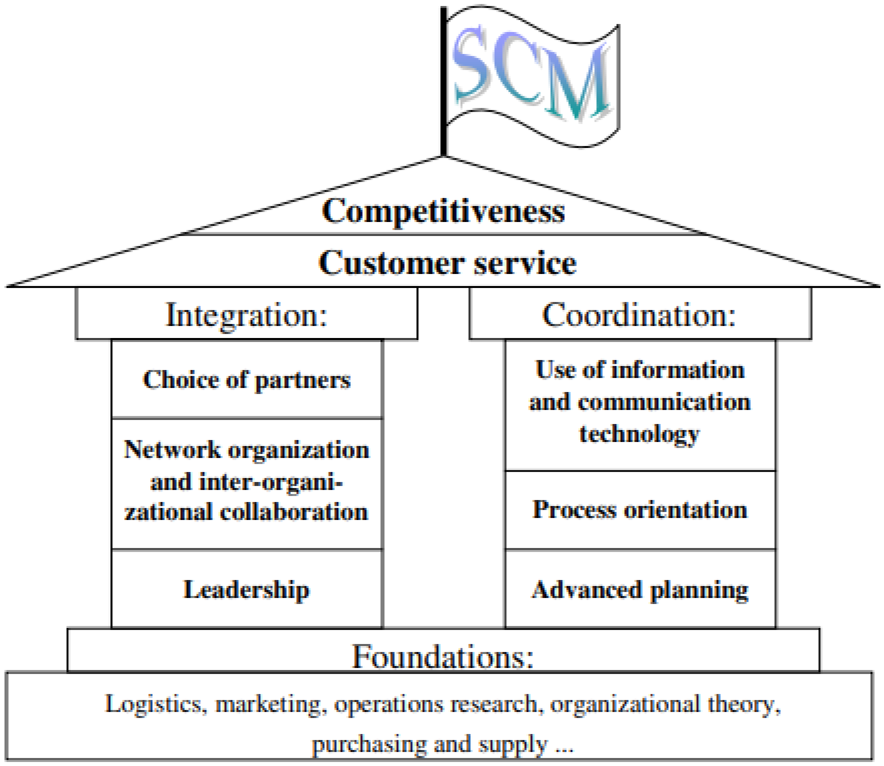

Figure 3. House of SCM. Source: Stadtler and Kilger (2005).

Complex and expensive software that integrates resource planning throughout a supply chain exists, but often there is not transparency between companies. Manufacturers may want to hold onto their proprietary processes and intellectual property to keep a competitive advantage. This drives supply chain managers to plan with limited information, often the inventories on hand, the contractual delivery orders, and constant communication (Stadtler and Kilger 2005).

B. SUPPLY CHAIN DEVELOPMENT

Supply chains may look very different depending on the size and product produced, but the fundamental processes behind a successful supply chain can be generalized. General international standards, such as ISO 9001, set core expectations and requirements of quality systems. ISO 9001 sets expectations for many facets of a quality system, some of which are: monitoring and measuring production equipment, controlling and implementation of design changes, records for traceability, and a nonconformance identification and correction process

(Keen 2019). The ISO certification process also includes an independent registrar who audits the facility to the ISO 9001 and ultimately decides if the facility meets the standard.

Attaining an ISO 9001 certification shows that a company has the fundamentals of a Quality Management System (QMS), but it may not mean that the company is postured for success in a supply chain. L. Shrimali identified seven steps to identify, assess and qualify new vendors in a supply chain (Shrimali 2010). These steps are listed in Table 2.

Table 2. Seven Steps for Supplier Quality Evaluations

Step	Description	Explanation
1	Identifying critical commodities	This includes identification of supply chain materials or parts that a design or assembly company are not willing to make themselves.
2	Identifying critical suppliers	Cross reference the list of parts needed with companies who identify this as their core competence.
3	Forming a cross functional team	Form a team of all specialties (e.g., engineering, finance, program management) to determine the cost, schedule, and performance requirements.
4	Meeting with supplier top management	Meet with the supplier and discuss the cost, schedule and performance requirements determined in step 4.
5	Identifying key project metrics	The two companies agree on core requirements needed to make the business relationship successful. These are monitored with the QMS discussed above.
6	Defining details of agreement	More tangible details such as delivery quantities and unit price are discussed and agreed upon, normally leading to a contract between the two companies.
7	Monitoring status and strategies	As the contract is executed, the expectations set forth in steps 5 and 6 are compared to the supplier's actual performance, and adjustments are made if needed.

After all these steps are conducted, there is often a final validation step called a First Article Inspection (FAI). This inspection is conducted on the first lot of material a supplier produces for their customer. Up to this point, the company has shown a QMS capable of monitoring and producing conforming parts, and there is a contractual agreement in place that sets targets for metrics such as cost or throughput. The FAI proves the manufacturing line set up to produce the customer's part is working as intended (Partida 2020). This inspection is very invasive, sometimes destructive, and it validates all characteristics and notes on the detailed drawing provided by the customer. Destruction of the part may be necessary to cross section areas that may otherwise not be inspectable during normal operation, such as an internal metal cast feature. This step proves to both the company and their customer that they can build the part as expected.

The generalized guidance that ISO9001 and the Shrimali process provides can prove beneficial in my research. Since the APP deals with a variety of materials, components and systems, general processes that provide guidance regardless of the product can be helpful to set expectations and measure compliance across the enterprise.

C. SUPPLY CHAIN MANAGEMENT

According to Monczka, Trent, and Handfield, "Supply Chain Management (SCM) requires traditionally separate materials functions to report to an executive responsible for coordinating the entire materials process, and also requires joint relationships with suppliers across multiple tiers. SCM is a concept, whose primary objective is to integrate and manage the sourcing, flow, and control of materials using a total systems perspective across multiple functions and multiple tiers of suppliers."

SCM is an ongoing process throughout a product's life cycle. Successful supply chains have the following general characteristics, as stated in the *Journal of Business Logistics* which is shown in Table 3 (Mentzer et al. 2001).

Table 3. General Characteristics of Successful Supply Chains. Source Mentzer et al. (2001)

1.	A systems approach to viewing the supply chain as a whole, and to managing the total flow of goods inventory from the supplier to the ultimate customer.
2.	A strategic orientation toward cooperative efforts to synchronize and converge intrafirm and interfirm operational and strategic capabilities into a unified whole; and
3.	A customer focus to create unique and individualized sources of customer value, leading to customer satisfaction.

Constant management of a supply chain is required because the system can be dynamic. Internal to the product supply chain, factors such as personnel changes necessitate new employees to be trained. Any new equipment or design changes to the product may require a new FAI on the drawing characteristics affected by changes, requiring the training updates to match. New training instructions must be reviewed and verified to ensure the employees understand the changes and are performing the new process properly without any unintended consequences that may cause unintended outcomes.

There are also external factors that indirectly impact supply chains. For example, if a supplier receives a more lucrative contract that shares the same equipment or personnel, resources may be diverted to that other project at the expense of the original supply chain. Alternatively, if other contracts end or are terminated and the supplier cannot be profitable with only the supply chain's product line, the supplier may go out of business even if all direct measures (cost/schedule/performance) are on target.

Due to the constant changes and interdependencies that drive complexity within the supply chain, management is constant and crucial to the long-term success of the product line. To reduce risk, supply chain managers may qualify multiple vendors for the same part. This allows the supply chain manager to diversify their risk across multiple suppliers so there is no single point of failure within the supply chain. This also allows the supply chain manager to compare the two company's price, yields and schedule performance to each other, and identify strengths and weaknesses in the companies that may not be observed without direct competition.

Like the generalized quality guidance in Section B, this supply chain management characteristics manage to distill the necessary functions of a supply chain to be universal. While some of the material may need to be refined for PPE, this provides a basis to build upon.

D. MONTEREY PHOENIX

Monterey Phoenix (MP) is a tool developed by Naval Postgraduate School (NPS) to model behaviors and interactions between and among systems. MP creates permutations of processes so that subject matter experts can interpret possible scenarios and introduce requirements through an iterative process to preclude them from occurring when a system is deployed. This section discusses past theses and articles regarding applications of MP to provide inspiration for supply chain modeling.

Amanda Rowton applied MP to emergency responders in her thesis “Using Behavior Modeling To Enable Emergency Responder Decision-Making.” This application utilized MP as a training tool for responders to react to different situations. MP generated scenarios may be less frequent during a daily shift but carry a large consequence if the first responders do not act according to the training. These scenarios provide an opportunity to practice these infrequent events in a training environment that allows time for critical thinking and reasoning without the adrenaline rush or life-threatening risks. Maj. Rowton’s models results in a dynamic tool that utilizes many permutations of scenarios to keep first responders ready for a host of situations (Rowton 2020).

In their paper titled “Modeling and Verifying Business Processes with Monterey Phoenix,” Mikhail Auguston et al. show the application of MP for business models, very similar subject matter to the creation of the APP (2015). The paper discusses more intermediate uses of MP for a program management to use for cost, schedule, and performance. One of the former barriers to MP was the need to have a certain amount of computer programming knowledge, which was overcome by a new Graphical User Interface (GUI) that drastically reduced the knowledge requirement to utilize this tool (Auguston et al. 2015). The GUI allows a more expansive utilization and adoption of MP for use in the development of real-world systems such as the APP.

The Monterey Phoenix website offers examples to showcase different features of the software and scenarios that exhibit emergent behavior. Specifically, there is an example that connects producers and consumers through a supply office. This is a useful baseline example of how to utilize MP in a general production environment. Figure 4 shows a scenario output from the example code of how suppliers and producers can be coordinated through an intermediary. This example provides a valuable and relevant template to model more detailed and specific scenarios related to the APP.

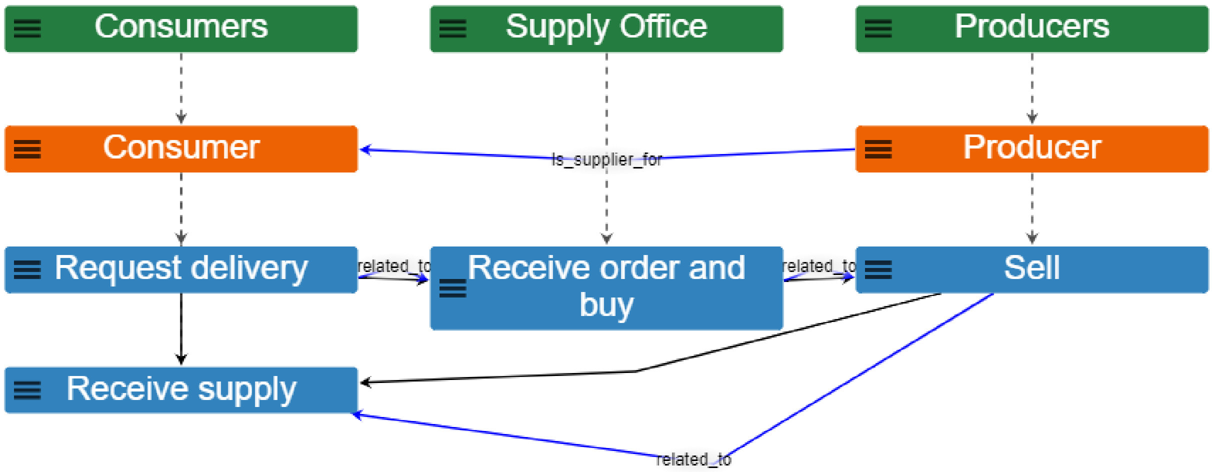

Figure 4. Consumer/Supplier Example from Monterey Phoenix

Nathaniel Alden, Rachel Talkington, Oybek Kamalov, and Noah Wells created a presentation titled "Application of Monterey Phoenix Modeling to Enterprise Risk Management" on October 9, 2020, at Naval Postgraduate School, Monterey. An applied example of MP and its resulting emergent behavior was conducted by modeling a cyber attack on the Colonial Pipeline. This team utilized MP to show what occurs when the petroleum industry and different military bases were exposed to cyber threats. They found multiple instances of emergent behavior by walking through each generated trace and making it a "story." By narrating how this trace can happen, it allows subject matter experts (SME) of the specific situation to recommend opportunities to constrain the unwanted behavior and improve the system overall. The impacts this team found are in Figure 5. The team plans to use these outputs as the basis for recommendations of additional requirements for the system. This strengthens the system from these types of cyber-attacks in the future. The same approach will be taken regarding the APP and create stories through an iterative process, which is discussed in detail in Chapter III.

Impact Types

Immediate

- Lost jet fuel
- Pipeline repairs
- Cost to clean up spilt jet fuel
- Lost intellectual property
- Inability to operate

Delayed

- Recalled jet fuel
- Explosions due to static build-up
- Planes lost due to corrosion and icing
- Lives lost
- Increased attacks of this nature

Figure 5. Consequences of a Cyber Attack on the Colonial Pipeline. Source: Alden, Kamalov, Talkington, Wells (2020).

III. BEHAVIORAL MODELING METHODOLOGY

The thought of preemptively predicting negative or harmful behavior can sound unrealistic or too good to be true. This chapter parses what MP does towards this objective step by step, based on recent advances in emergent system behavior analysis at NPS (Giammarco and Auguston 2018). In addition to building the models with the MP grammar and syntax, the methodology applied for detecting, classifying, and predicting both good and bad emergent behavior is discussed. Lastly, the ways of controlling that behavior to influence the impacts are considered.

A. INTRODUCTION TO GRAMMAR AND SYNTAX

Monterey Phoenix is a program to express relationships between separate entities. With a simple text-based event grammar, MP allows the user to create interconnected models. The output of these models is called an event trace. The example in Figure 6 shows a very basic event trace generated from MP.

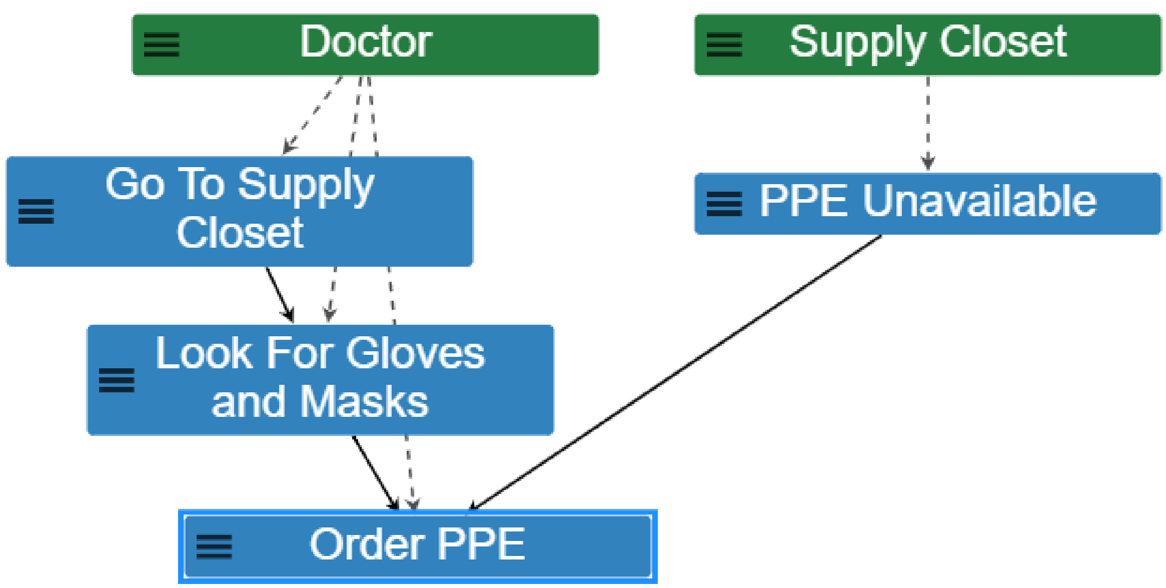

Figure 6. Basic Event Trace

The figure above details an interaction between a doctor and a supply closet of PPE. The green boxes in Figure 6 are called root events. Root events are top-level system activities that interact with other events described in the model but are not included within other activities. In other words, these are parent activities that has no parent themselves. The blue boxes are called atomic events. These events have the most defined detail and are often used to model specific steps in a process. There is one more event which is not illustrated above, called a composite event. The composite, normally denoted in MP as an orange block, is an intermediate event which contains many characteristics of a root event, but also has a root parent. Composite events are utilized to bundle similar or related atomic events. One could consider composite events a sub-system, that is a fully functional system by itself, but it must be viewed within the context of a larger system. Solid arrows show a structured precedence in the event trace sequence, while dashed arrows denote inclusion.

According to Auguston, the syntax used in MP is that of a "high level" programming language, more of a pseudocode language rather than a true programming language (2018). The MP schema is a title that names the model used to generate the set of event traces. Dr. Kristin Giammarco and Dr. Kathleen Giles created the Figure 7 and explained the corresponding grammar rules in a lecture titled "Exposing and Controlling Emergent Behaviors in System Models" on January 21, 2021, at Naval Postgraduate School, Monterey. In their presentation, they state: "…event grammar rules with the basic structure (upper left) can be extended with syntax for other behavior patterns such as alternate (upper middle), optional (upper right), zero or more iterations (lower left) or one or more iterations A: (+ B +)."

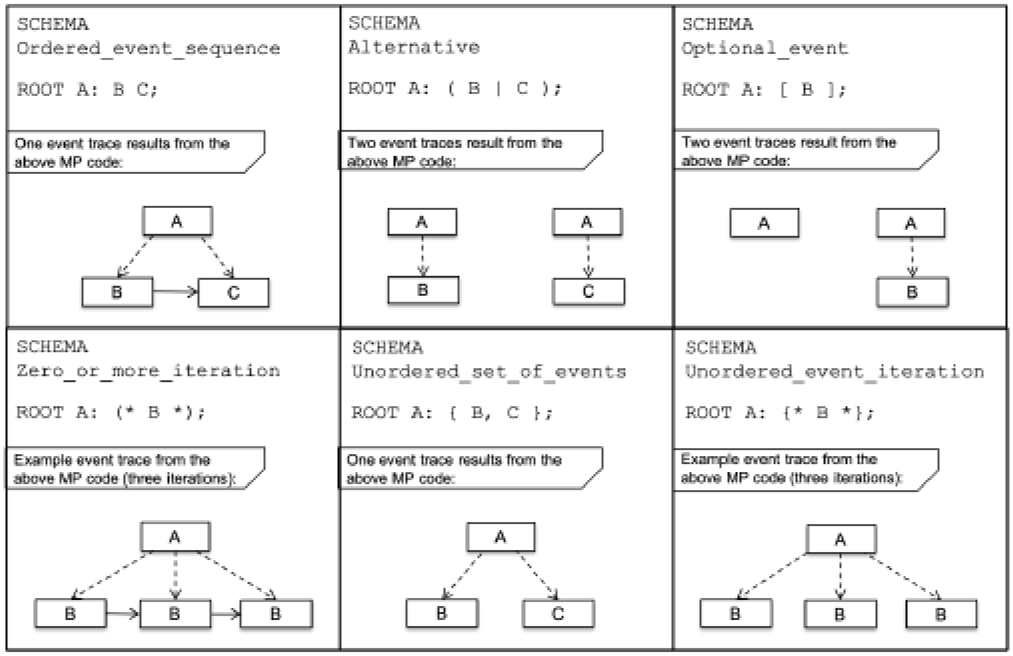

Figure 7. Grammar Rules

Coordinate statements act as the forcing function for precedence (solid arrows) between and among events in different roots like the ones in Figure 6. As an example, Figure 8 shows the code of a coordinate statement detailed later in this thesis. Each of these coordinate statements follows the same syntax. First, a specific atomic event is defined from the parent root as "$x." The other atomic event that relates precedence is defined from their parent root as "$y." A "DO" statement follows that defines $x precedes $y.

```
COORDINATE  $x: PPE_Available, $y: Take_PPE
        DO  ADD $x PRECEDES $y; OD;
COORDINATE  $x: PPE_Unavailable, $y: Order_PPE
        DO  ADD $x PRECEDES $y; OD;
```

Figure 8. Coordinate Statements

MP offers the ability to comment out code temporarily. The syntax to temporarily remove coding is by adding "/*" before the code and "*/" after the code. When models are over-constrained, commenting out coordinate statements is utilized to systematically open the aperture of the model and look for plausible scenarios with an extra degree of freedom.

B. WRITING AND RUNNING TRACES

By combining the syntax of MP with anecdotal knowledge of specific interactions, discrete events were created to parse for behavior. Figure 9 shows code on the left-hand side, and the two resulting event traces on the right. The SCHEMA describes the overarching interaction, which is obtaining PPE. Two ROOTs are defined as stakeholders in this model, a doctor, and the supply closet. Each stakeholder has processes coded as atomic events. In the doctor's case, the order of atomic events sets a built-in precedence that is graphed using the solid arrows. The supply closet has two atomic events embraced in an "or" statement. The supply closet either has PPE, or it does not.

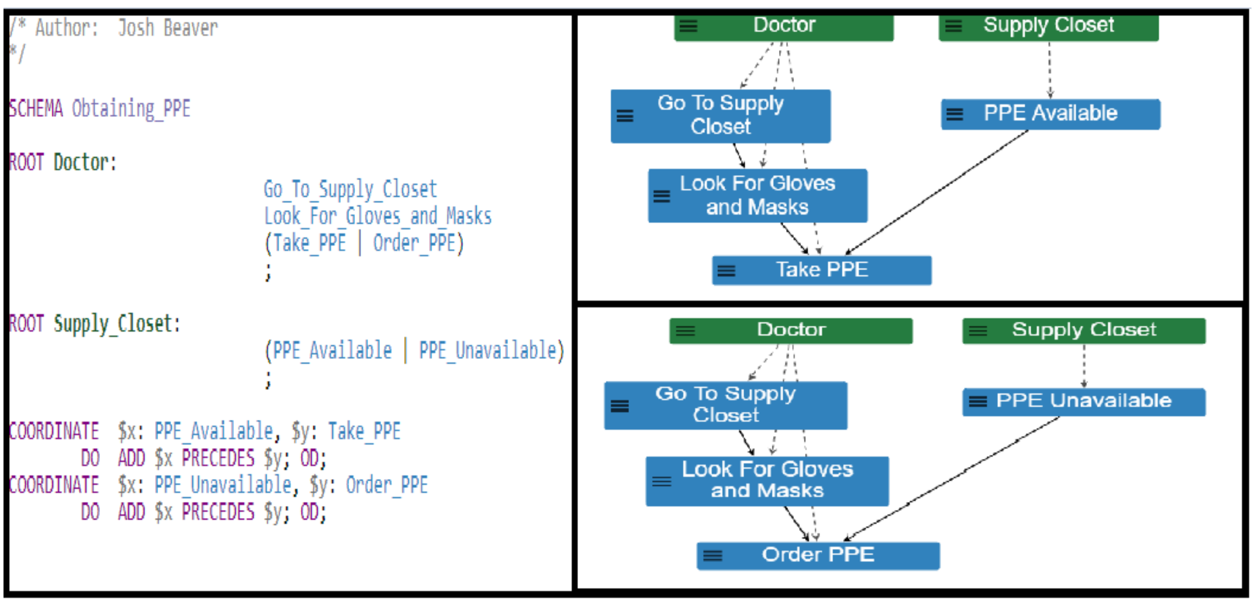

Figure 9. Code and Traces

After creating the SCHEMA and ROOTS and their corresponding atomic events, the model compiles and executes properly. However, some of the initial results do not make sense, necessitating the use of coordinate statements to only display realistic alternatives. For example, a trace such as Figure 10 appears. A person analyzing these traces could create a story to explain the outputs. It could be assumed that the doctor was unable to find PPE in the supply closet, and instead went into their personal PPE collection they'd saved for this occasion. The two coordinate statements in Figure 8 tell that model that the doctor only takes PPE if it is available and if the PPE is unavailable, to order the PPE.

Figure 10. Unconstrained Trace

C. DETECTING AND PREDICTING EMERGENT BEHAVIOR

A closer look at the coding and resultant event traces reveals emergent behavior which had not previously been discovered. This is behavior that is not expected or intended but is possible when event traces are analyzed. The intention of the second coordinate statement in Figure 8 is to order PPE when the supply cabinet does not have any available. In actuality, the coordinate statement only allows for ordering PPE when the supply cabinet is empty, which implies there could be a period where doctors are without vital equipment. Now that this realization is discovered and documented, this event in MP is reclassified from an unexpected event to one that was identified, now expected, and controls can be created to manage the likelihood of this outcome.

The explored model takes a small piece of a larger system to find the root cause of a problem causing secondary and tertiary impacts to the hospital. MP allows analyzing each event trace as an individual story to decipher realistic scenarios, along with resultant emergent behaviors.

The emergent behavior can be both good and bad and can possibly be exploited or controlled if identified ahead of time utilizing MP.

D. CONTROLLING EMERGENT BEHAVIOR

To control emergent behavior, the user needs to ruminate about what is desired and undesired within the SCHEMA by the different ROOT actors. There are many ways to react to the possible lack of PPE. In Figure 11, the emergent behavior can be controlled in MP by training the doctors and making them accountable to reorder at a predefined low inventory level. To model this, the previous binary options are built upon to create a third option for both the doctor and supply closet, which has an indicator that supply is low. There is also a third option for the doctor to both take PPE and reorder PPE.

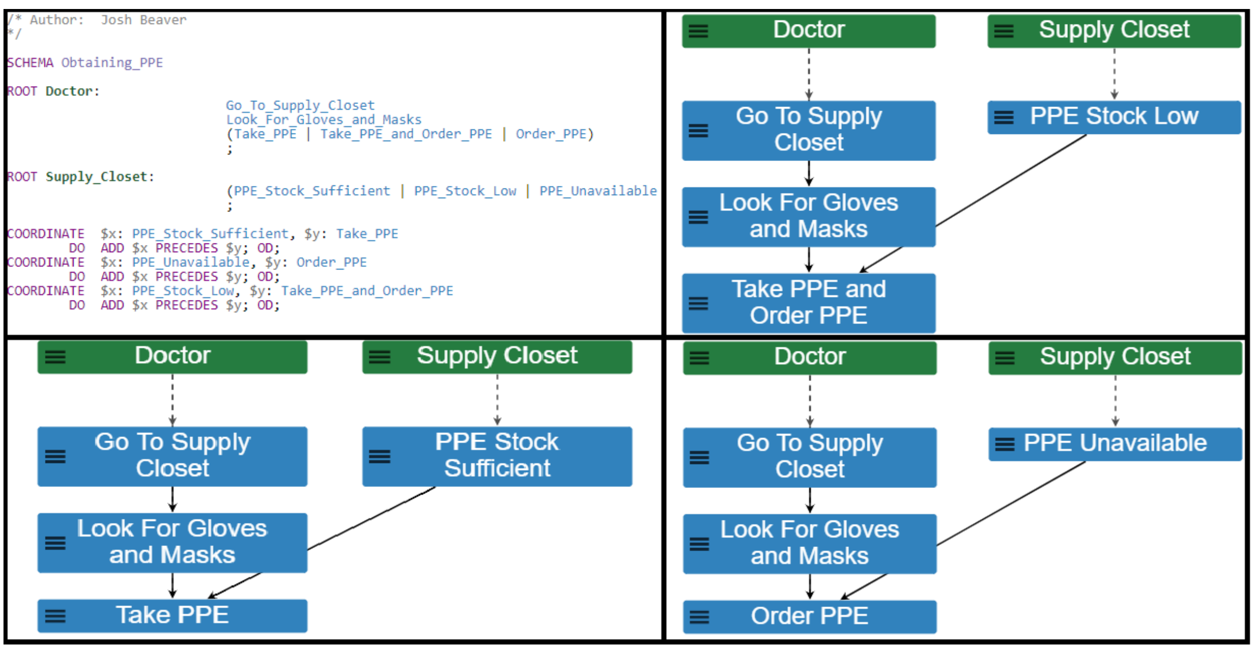

Figure 11. "Low Stock" Option Added to Refine Outputs

There may be limitations in the hospital that inhibit controls that are deemed appropriate through MP, such as personnel availability. In Figure 12, an inventory manager is added to the model as an alternative scenario that addresses the same emergent behavior. The coordinate constraints are transitioned from the doctor to the inventory manager, which frees up the doctor to take PPE in every scenario. This way, the desired behavior of doctors taking PPE is maximized, while the chance of low PPE stock is minimized, and that is validated by the updated model in Figure 12.

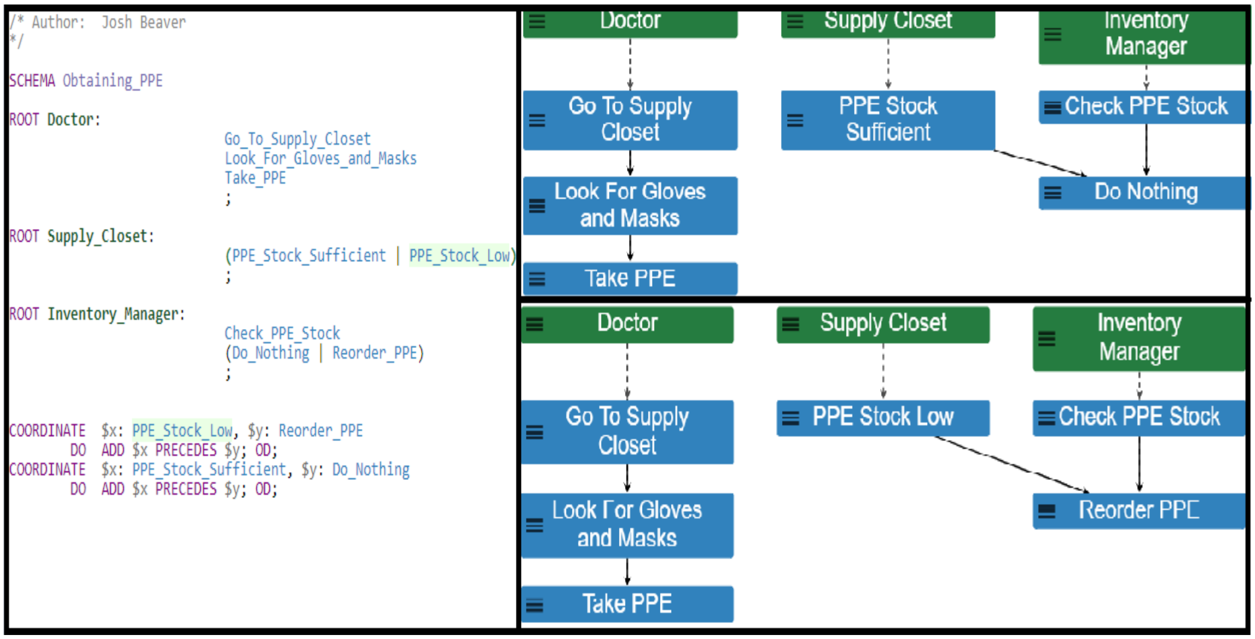

Figure 12. Inventory Manager Added to Control Behavior

These simple scenarios provided a basis to identify and analyze a quick interaction between stakeholders. The MP model and subject matter expert must iterate event traces to reflect the current situation and explore emergent behavior, classify that behavior, and control the behavior with additional stakeholders or constraints via coordinate statements. In Figure 12, the outputs could be further refined by adding a constraint that a doctor can only take PPE if the supply closet shows sufficient or low stock. By using MP as a guide, the root cause of a problem was narrowed down and controlled in different ways, finally verifying it using MP. Chapter IV expands the scope of supply interactions and PPE stakeholders to a macro scale as it relates to the APP.

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IV. MODEL SCENARIOS AND RESULTS

This chapter focuses on the two separate scenarios modeled within MP to explore emergent behavior, and the results from each. Supply chains vary widely, and the original attempt to model a singular scenario which controlled for many possibilities created more permutations that could practically be studied. Instead, three plausible scenarios of how the APP may interact with suppliers and/or customers are investigated.

A. TRANSPORTATION AND DELIVERED QUALITY

1. Initial Scenario for PPE Transportation

The goal of the APP is to provide compliant PPE to healthcare workers and the public. This scenario explores whether the introduction of the APP as a medium of exchange presents unintended consequences that could be interpreted as unexpected emergent behavior.

Imagine that there is a metropolitan hospital, where a COVID outbreak strained the capacity and PPE supplies. Historically, the hospital procured PPE through a distributor. This distributor has a contract with mask manufacturers, and each of those manufacturers have contracts and manage their individual supply chains. This is a standard procurement example and is illustrated in Figure 13.

Figure 13. Legacy Supply Chain Example. Source: Long (2020).

The APP process, as discussed earlier, varies significantly from these disparate supply chains. The hospital customer may order directly from the APP or continue to buy from the distributor who procures PPE from the APP. This hospital is less concerned with the method of procurement if it receives PPE for the healthcare workers.

This scenario investigates emergent behavior that exists with the introduction of the APP which impacts the customer. The emergent behavior being sought could be any undesired experience for the customer when compared to the legacy supply chain.

2. MP Baseline Model Scenario

The models in Figure 14 and Figure 15 created in collaboration with Dr. Kristin Giammarco illustrates the relationship between the end customer and the APP system. Dr. Giammarco created the model while I used my supply chain knowledge to refine the results, tell the stories of the traces and recommend changes. The customer utilizes the system as expected, by logging in to the APP and searching for necessary supplies. The APP reviews the database of PPE and displays matches. The customer reviews the matches and selects the best fit for their needs.

This model displays a nominal scenario between the APP and customer, where the system works as intended. The customer is connected with a PPE supplier through the APP's integrated database and fulfills the intent of the Agile Production Platform Concept detailed in Figure 2. However, this model takes for granted that the customer receives the item and is satisfied with the purchase.

The model was revised to include the addition of transportation and customer reaction to the product, as well as more fidelity with the supply chain as seen in Figure 15. This new model provides a more comprehensive view of the APP system, which allows for better analysis and possible detection of emergent behaviors. For the remainder of this section, the different scenarios from the model in Figure 15 are discussed.

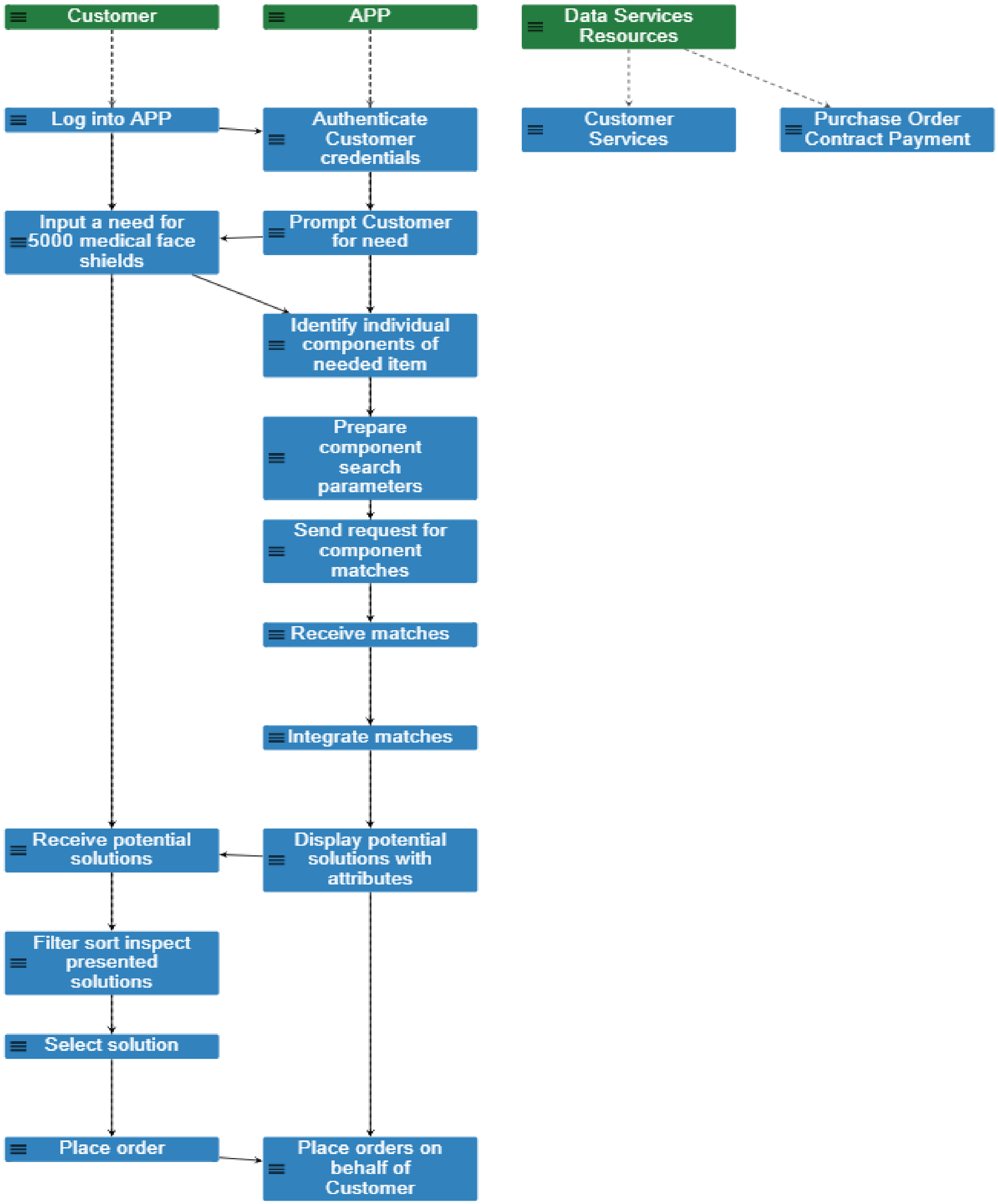

Figure 14. Initial Model between Customer and APP

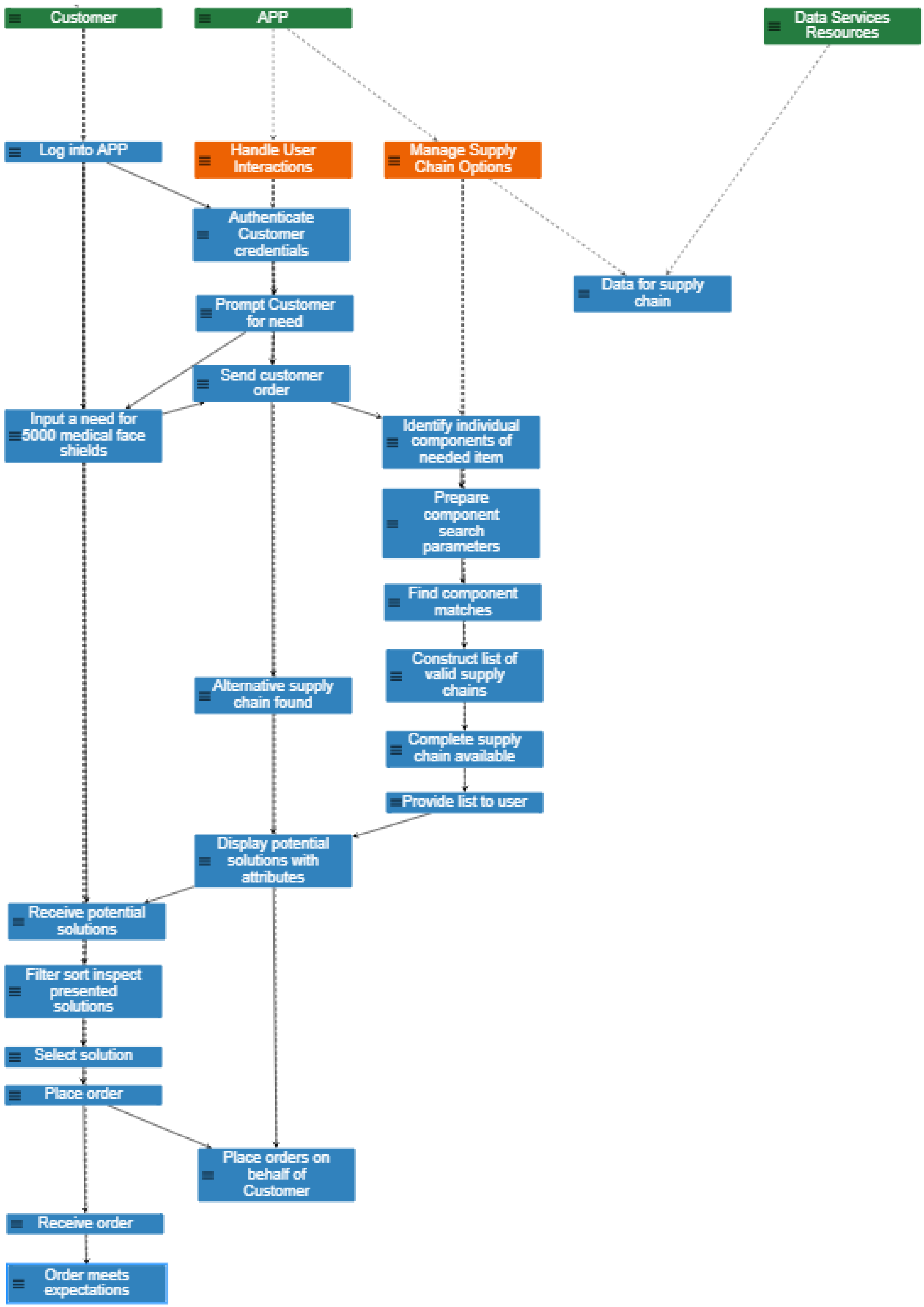

Figure 15. Revised Model between Customer and APP

3. Expected Undesired Outcomes of the Model

Unfortunately, it is unlikely that all customers will have a positive experience with the APP. When acting as a marketplace or integration point for disparate entities, there is inherent reliance that the different parties must fulfill their obligations. However, in a marketplace system that is decentralized, there is a tradeoff that favors speed of delivery rather than full control of all parties. The APP is only acting as an intermediary, but since this is the interface for the customer, the APP may receive the blame in undesired events.

Figure 16 details an expected scenario, considering the same scenario was prevalent during the COVID-19 Pandemic and one of the events necessitating the creation of the APP in the first place (CDC 2020). In this scenario, the customer and APP have a nominal interaction at first where the customer searches for PPE, the APP searches its database and finds listings, the customer selects the PPE and the APP places an order on the customer's behalf. However, the interaction breaks down when the customer never receives the PPE.

There are multiple reasons to expect this scenario. For example, the supplier may have made a mistake when displaying how much product they have ready to ship. The most likely reason is that the shipment is lost or delayed in transportation due to the delivery service. The APP is specifically designed to reduce the occurrence of these scenarios by centralizing information about PPE material, components, and systems, but human error may still occasionally introduce this scenario.

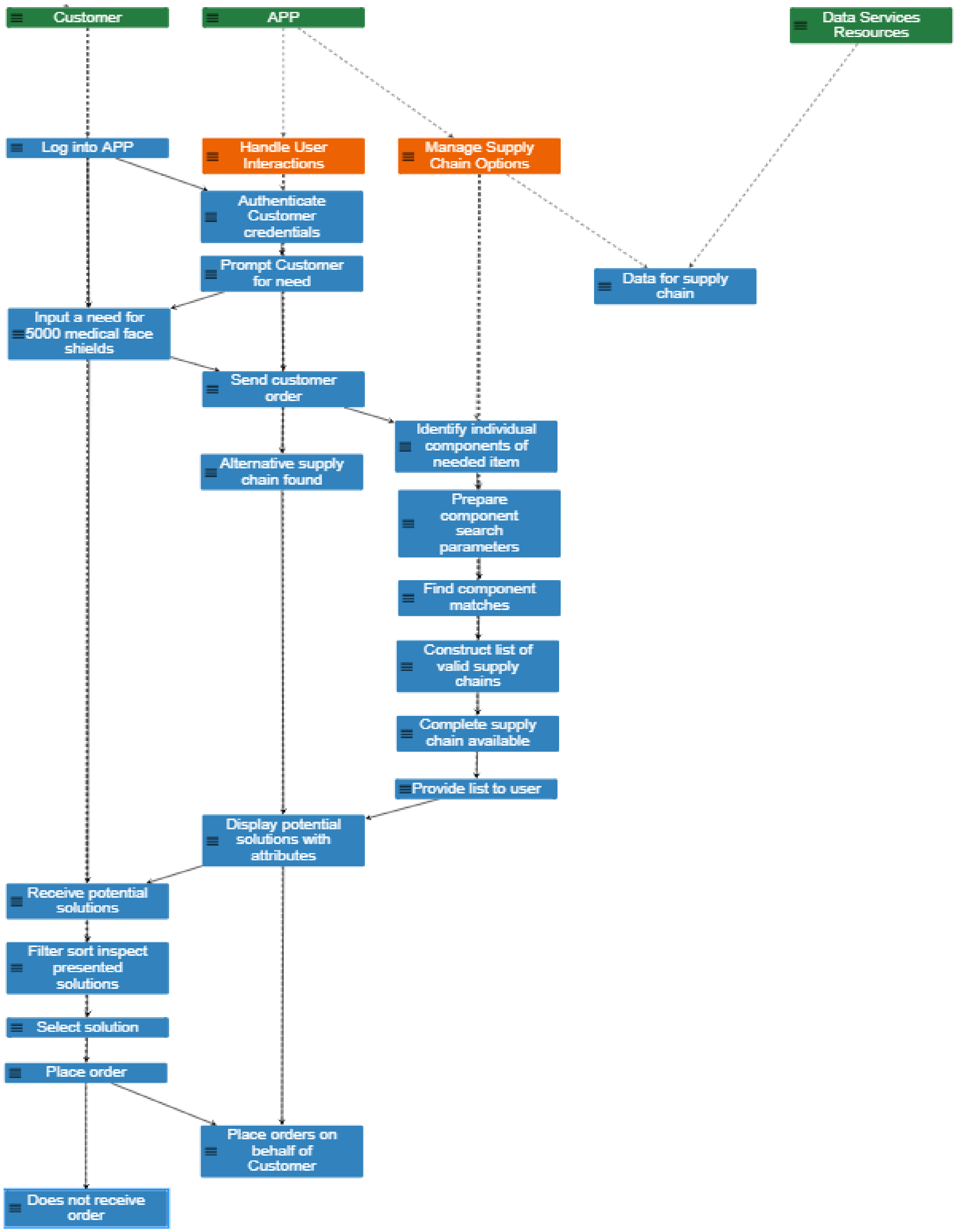

Figure 16. Expected Undesired Behavior- Package is Lost in Transit

4. Unexpected Undesired Outcomes of the Delivered Quality Model

During the analysis of this model, specifically the transportation section, a possible scenario which includes unexpected emergent behavior was discovered. Figure 17 is very similar to the expected undesired behavior described above in Figure 16. However, the unexpected emergent behavior lies within the block "Order Does Not Meet Expectations." Of course, there are expected reasons the product could be delivered and not meet expectations. For example, the PPE could be damaged during shipment, or the product could be the incorrect quantity. During analysis, another possible example was found that fits this scenario and was previously undiscovered.

Imagine a scenario where a hospital orders face shields through the APP. This hospital has utilized the APP multiple times in the past for face shields and never had a problem. This time, it appears to be another successful acquisition. The hospital accesses the APP and searches for 5,000 face shields. The APP connects them with a supplier that can provide them quickly and the hospital places the order. The order is shipped quickly and arrives at the hospital in the correct quantity. These face shields appear fine and are added to stock with the other face shields at the hospital.

At this point, one might consider this a success and move on. However, what if the glue holding the clear face shield in place fails the first time they use it while examining a COVID patient? What if the plastic restraint on the doctor's head fractures because it is a cheaper or thinner plastic? The overarching emergent behavior is the introduction of counterfeit materials in the APP supply chain that turns an initial successful interaction into an unacceptable situation. Consider this same scenario but applied to the filter of an N-95 mask detailed in Figure 18. A doctor could rely on the protection of this mask that appears to be genuine, but the filter could be counterfeit and expose the doctor to COVID-19 even if they are taking all proper precautions.

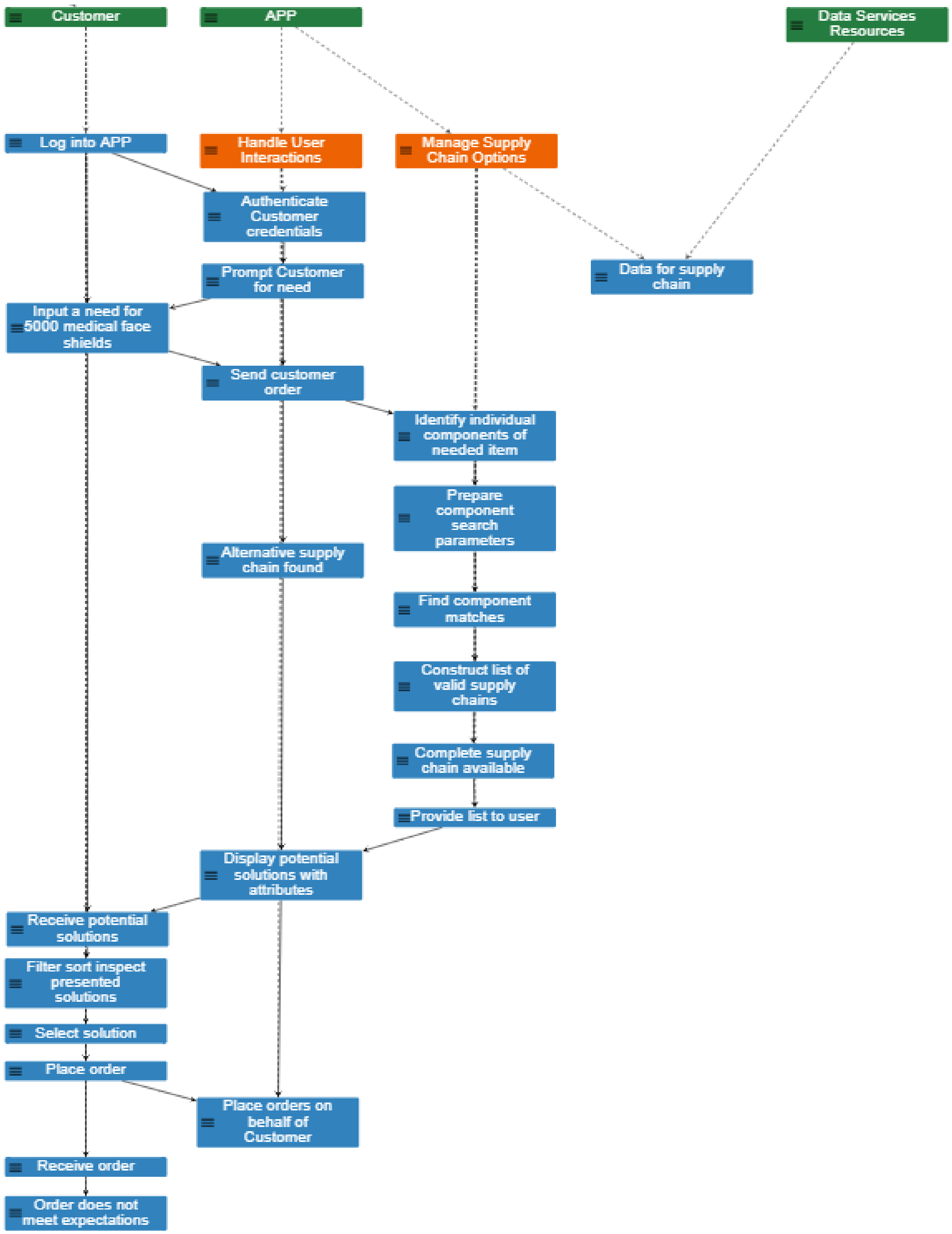

Figure 17. Unexpected Possibility of Counterfeit or Defective PPE Delivered to the Customer

B. MATERIAL FLOWING THROUGH SUPPLY CHAIN

1. Initial Scenario for PPE Material Flow

Supply chains for PPE can vary in size and complexity. For this scenario, the hypothetical sourcing of a moderately complex piece of PPE, the N-95 mask, is discussed. The N-95 mask contains seven discrete components, highlighted in red in Figure 18. These red components have their material compositions or sub-components listed in gray below each of them. Using this information, it becomes easier to visualize the N-95 supply chain. One mask made up of seven discrete components, each made up of at least one raw material or sub-component creates a hierarchical production system.

Figure 18. N-95 Mask Components. Source: Quan (2020).

One of the unexpected events that occurred during the early stages of the COVID-19 pandemic was that PPE manufacturers were sourcing their materials from some of the same lower-level suppliers (Park et al. 2020). This supply chain structure caused the PPE manufacturers to share the same supply bottlenecks across the multiple chains, which resulted in PPE manufacturers taking on more risk than they realized. Without the needed sub-components, the PPE was incomplete and could not work as advertised. Some benefits discussed by the APP in Chapter I is a centralized, open marketplace of both finished product and all tiers of components and raw materials rather than disparate supply systems that may be unknowingly interconnected.

As an example, for this scenario, imagine a large, well-known business that designs, assembles, and sells N-95 masks like the one described in Figure 18. The business has multiple suppliers for the seven distinct components of the mask, each of whom have multiple suppliers for materials. The N-95 competitors have supply chains of similar scope and magnitude. In Figure 18, the shell and coverweb use the same polyester material, possibly causing a shortage of polyester like the situation described earlier in this section.

This scenario explores emergent behaviors that may have unintended consequences for either the APP or one of its users. Scenarios of components manufactured through multiple levels of value-added production and distributed through the APP are explored to determine if controls exist to identify and control quality escapes.

2. MP Model of Typical Event Flow

This example shows the fundamental goal of the APP, which is to act as an intermediary between the customer and suppliers to build an ad-hoc supply chain where every supplier has the technical knowledge, capacity, and material on-hand to produce the component correctly. Figure 19 details a nominal interaction where every interaction resolves satisfactorily. The customer orders a product through the APP, and the APP sends requests to all suppliers and coordinates material deliveries between them. All suppliers make a conforming product, validated by inspections, and ship it to the next manufacturer. Once the product is fully manufactured, the finished product is shipped to the customer.

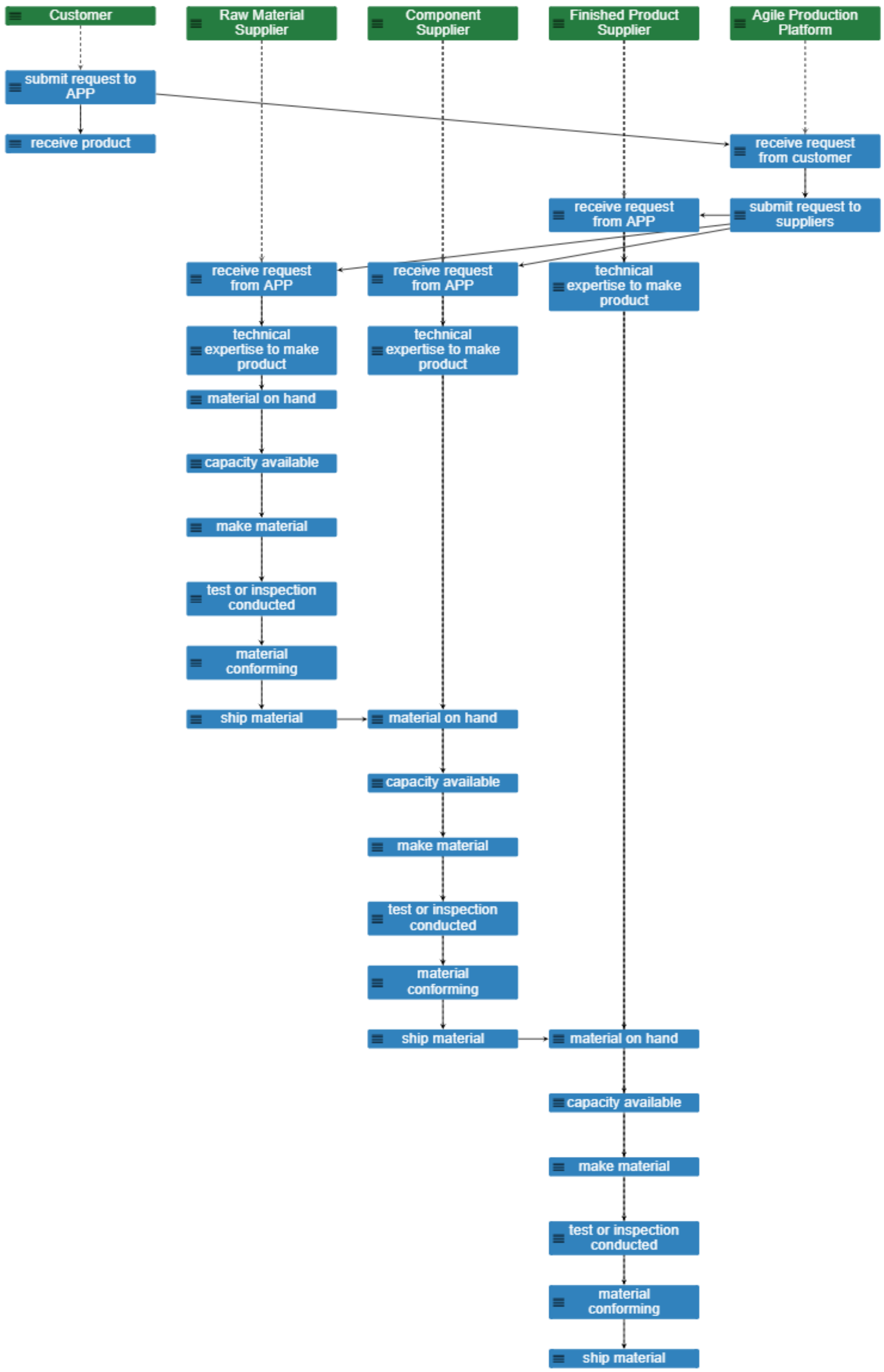

Figure 19. Example of Nominal Material Flow through Supply Chain

3. Expected Undesired Outcomes of the Model

It is safe to assume that not every interaction through the APP is perfect. There may be times where one or more stages of the supply chain do not have the expertise, material, or capacity to build the proper product. This could be because the customer desires a very peculiar part that is not normally made, or that there is so much demand for certain products that all tiers of able component suppliers could be at max capacity.

Figure 20 details an example where a customer makes a request to the APP but is unable to get the item. The raw material supplier can complete all their steps and ship product, but the component supplier has no capacity left to fulfill the order. This causes the finished part supplier to idle while waiting for the proper components to fulfill the customer's order.

This hypothetical scenario is still possible while utilizing the APP, even though it is a foundational example of why the APP began development. However, the likelihood of this scenario should be substantially less due to the open-source nature of matching manufacturers through the APP compared to the current disparate supply chain models for PPE.

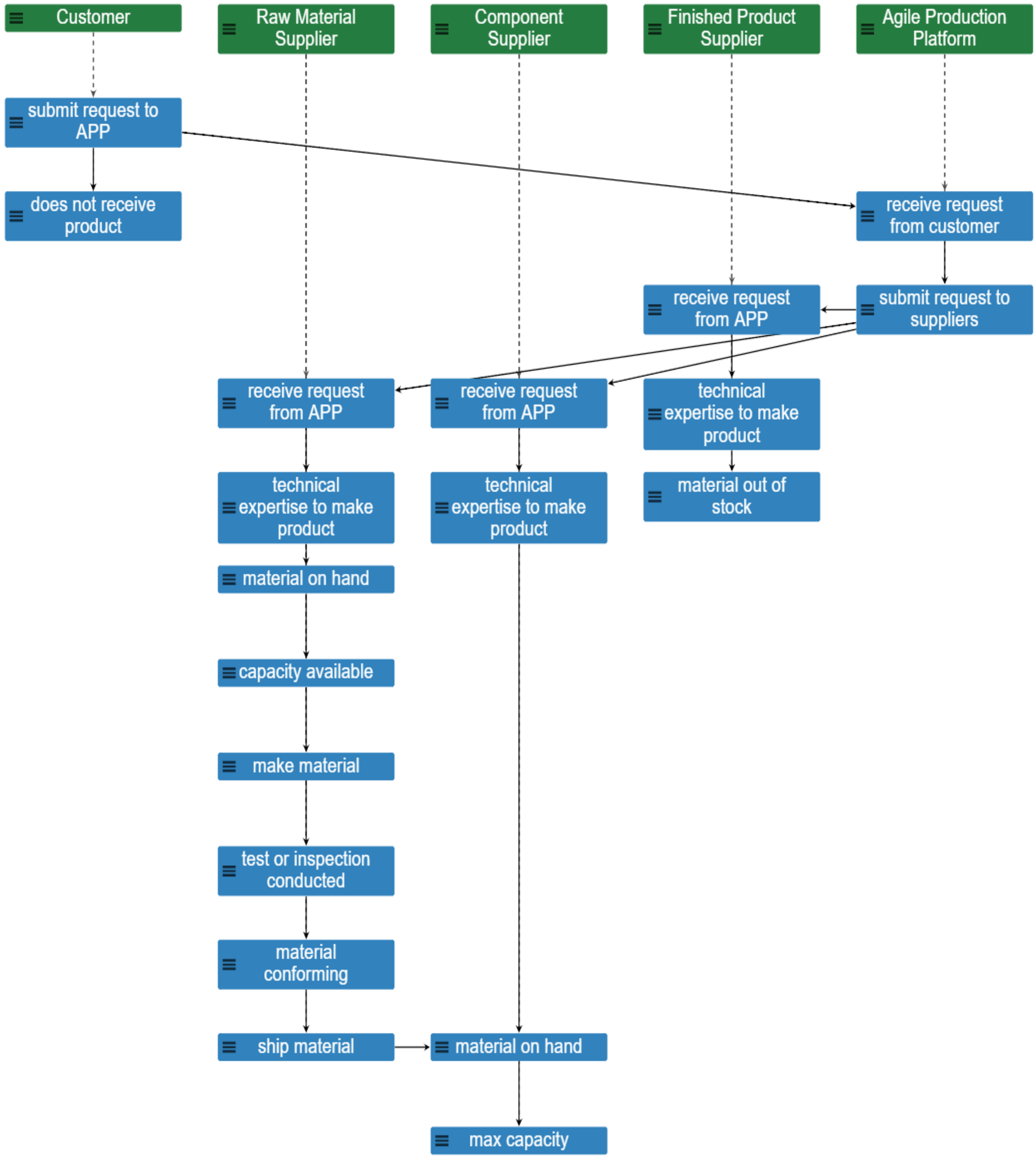

Figure 20. Expected Undesired Behavior- Supplier Experiences Capacity Constraints

4. Unexpected Undesired Outcomes of the Supply Chain Model

The previous scenarios discussed expected desired behavior and expected undesired behavior. Analysis of the many possible iterations of this model also uncovered some possible models that were not expected. This example details a possible interaction between stakeholders that looks successful initially, but a closer analysis indicates outcomes that could have devastating consequences.

In Figure 21, the interactions begin as expected with the customer placing an order through the APP, which then coordinates suppliers. The raw material supplier produces the product and elects to not conduct an inspection, either because it is not required for the part, is only done on a sample of products, or another reason that is innocuous. Either way, this material ships as expected to the next higher assembly manufacturer.

The component supplier builds up the product and conducts an inspection. This material is nonconforming, but it still ships. There are multiple plausible reasons for this. First, the inspector may recognize the nonconformance, inform engineering and/or management and get their professional analysis that the nonconformance does not impact the product. Also, the inspector may have inadvertently passed the product due to human error, bypassing controls for nonconforming material disposition.

The finished product supplier assembles the product and elects not to conduct an inspection. For assembly of simple components, this is not uncommon. The finished product supplier may not have the equipment or expertise to conduct some of the component testing, which is often a driving factor to outsource components. The finished supplier boxes up the PPE and sends it to the customer. Note that the customer receiving the product is not directly dependent on the supplier shipping the material. During analysis, it appears that this constraint may remove some emergent behavior, so the dependency was removed and traces were rejected manually if they were impossible.

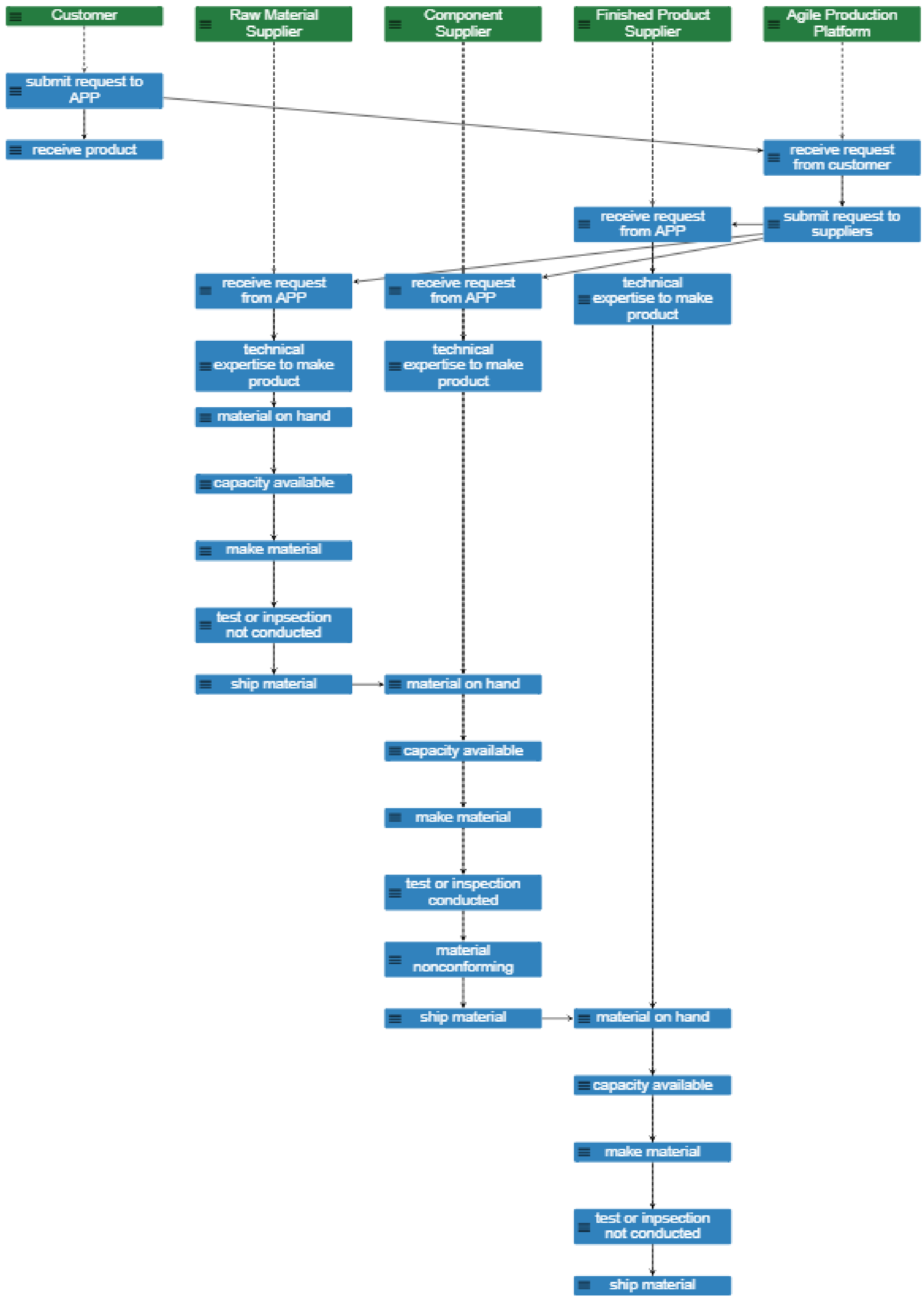

Figure 21. Unexpected Undesired Example of Customer Possibly Receiving a Defective Part

This hypothetical scenario results in a customer receiving a part that is not built to the standards expected. In a pandemic environment, unknowingly using nonconforming PPE could be hazardous to the customer's health and jeopardize faith in the APP marketplace. Due to the possible ramifications of this event, controls should be implemented to discourage or eliminate this undesired event.

V. CONCLUSIONS AND RECOMMENDATIONS

The intent of this thesis was to create plausible scenarios between stakeholders of the APP and analyze them for emergent behavior in MP before these events are experienced in an operational environment. A subset of scenarios related to supply chain from the APP were compiled with the help of stakeholders developing the system and subject matter experts on supply chain. A nominal model was built and studied viable alternative scenarios that could present unexpected or undesired behavior. The first model resulted in only four alternative scenarios after all constraints were added to make the possibilities realistic. The second model presented 109 permutations of supply chain interactions.

Model iterations were reviewed exploring methodologies to approach the research objective of whether emergent behavior exists that could undermine the performance or perception of the APP. The models show expected successes, as well as behavior that resolved in expected failures and some unexpected failures. This information allows the APP development team to proactively control the behaviors that emerged, resulting in a better user experience for both suppliers and customers.

The first instance of unexpected emergent behavior uncovered was that the products delivered to healthcare workers may not be what's expected. This could be an obvious instance, such as when the quantity provided does not match what was ordered, or the product was not packaged properly and damaged during shipping. It was also discovered that a counterfeit part could fit in this scenario. The counterfeit scenarios range from moderately troubling to severe. Counterfeit PPE that protects adequately but breaks prematurely is most likely a frustration rather than a hazard unless the PPE breaks at an inopportune time and exposes the user to a contaminated environment. A counterfeit mask that looks and feels genuine could expose healthcare workers to toxins and decrease confidence that masks are effective, which undermines one of the reasons the APP was created.

Lastly, some emergent behavior was exposed within the supply chain construct where the APP is an intermediary. Expected emergent behavior was found in instances where some industries are at max capacity even when the APP pools resources from multiple disparate supply chains.

Unexpected emergent behavior was exposed where human error or faulty tests caused nonconforming material to continue through the supply chain. This was an example of defective parts, which are separate from the counterfeit parts above, that result in defective PPE. Both scenarios drive the same undesired effect of reducing confidence in both the APP and the PPE it produces.

A. RECOMMENDATIONS

Supply chain experts were utilized to provide analysis of the models and recommendations to proactively protect the APP against the unexpected emergent behavior found. More direct and effective controls could be implemented on a product-by-product basis. These recommendations are tailored at a strategic level for incorporation across the APP's enterprise to reduce the likelihood of the undesired emergent behavior.

The transportation and delivered quality model exposed some weaknesses but also showed opportunities to strengthen the system. First, there should be a customer feedback system for product that does not arrive as expected or perform as intended. That feedback can be analyzed for trends to expose problem suppliers. The APP can use this to impact positive change or remove them from the system as an approved supplier.

For possible counterfeit concerns, it is recommended that the APP require suppliers to abide by ISO 16678, guidelines for interoperable object identification and related authentication systems to deter counterfeiting and illicit trade (International Electrotechnical Commission and International Organization for Standardization 2018). PPE from a new APP supplier could also be validated by an FAI and/or third party to show conformance to critical characteristics and parameters prior to shipment to the customer. This may not be necessary for all PPE, but critical systems that utilize electronics and circuit cards which are highly susceptible to counterfeit such as ventilators could benefit.

The supply chain model that utilizes the APP as an intermediary to "handshake" different suppliers also exposed opportunities to strengthen the APP as a system. First, companies should be ISO 9001 certified at a minimum. This standard for quality management systems shows that they have a quality system in place, and standardized process to handle nonconforming product which has been verified by a third-party registrar. Like the customer feedback recommendation above, there should also be a supplier rating system to show the percentage of on-time deliveries and whether the material arrives conforming to the next higher assembly. There should also be a requirement to list any anomalies to dimensions or chemistry of the product, or if the product isn't tested or inspected. Many times, the deviation may be negligible, but companies may ship product without understanding the impact that deviation may have on the system at the next higher assembly.

B. FUTURE RESEARCH OPPORTUNITIES

This thesis may be applicable to other supply chain interactions, especially those where an entity acts as an integrator and may not have direct control over all sources. A comparable research opportunity may exist for Department of Defense (DOD) acquisition teams acting as the Lead Systems Integrator (LSI) of a system. These models could be tailored to match the supply chain of the system with additional detail specific to that environment. A supply chain SME could review the traces and determine if unexpected behavior exists within that system.

Another opportunity is to continue researching the maturation of the APP as it is developed and implemented. These models could be used as the basis, and then tweaked with any recommendations the APP team incorporates. Another iteration of models and analysis could be conducted to refine the system and find more emergent behavior since the APP system will have less degrees of freedom in the future.

Alternatively, this modeling methodology could be applied to the worldwide vaccination effort against COVID-19. Multiple companies utilizing their own supply chains are creating vaccine supplies for the entire world, and behavioral modeling could assist organizations in the procurement, storage, and distribution of the vaccine to maximize the effects to their population. Improvements in this system could benefit the populations of countries where the vaccine will not be abundant for some time, and countries that are mostly vaccinated but may need booster shots after an indeterminate amount of time to keep their population protected.

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APPENDIX A. DELIVERED QUALITY MODEL CODE

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Agile_Production_Platform_Customer_Interactions

created collaboratively in Teams by K.Giammarco, M. Collins and E.Griffor 08-20-2020
modified collaboratively in Teams by K.Giammarco and J.Beaver 09-17-2020


The "Agile Production Platform" (APP) represents the linkage platform being designed
to enable agile production / building of alternative supply chains.

The purpose of this model is to facilitate agreement on a baseline typical use case
for a Customer placing an order (for face shields, in this case) using the APP.

The model currently produces one (1) event trace at scope 1.  Reviewers of this model
are invited to provide feedback for better-named events, other events that may occur
normally or as a disruption to the sequence, missing or incorrect interactions, and
the partitioning of the high level APP functions for architectural cohesion. Lower-
level (implementation) activities have been deliberately omitted for now in order to
reach consensus on intended use at the highest level of abstraction.

Also invited are direct edits to the model that suggest alternatives for Customer
behaviors (including misuse and possible nafarious actions) and APP behaviors that
would correspond to the new Customer behaviors.

Since there is no concurrent editing capability at present, feedback may be delivered
to kmgiamma@nps.edu, mdcolli@evoforge.org and edward.griffor@nist.gov as:
- comments in the body of an email
- updated MP model with editor intials appended
    - may use SAY statements to attach comments directly to events in the event trace
      as demonstrated herein


***************************************************************************************

The narrative for this baseline use case is as follows:

Precondition: A Customer has an urgent need for 5,000 medical face shields.


1.  Customer logs into the APP linkage platform.

2.  APP authenticates valid customer credentials and prompts the Customer for the need.

3.  Customer inputs a need for 5,000 units of a medical face shield with desired
    attributes.

4.  APP identifies the individual components of the needed item.

5.  APP determines which Sector Resources to search for equivalent components (prepares
    component search parameters).

6.  APP searches Sector Resources for available component matches and their attributes
    (e.g., availability, timeliness, cost, reliability, quality, quantity).

7.  APP assembles combinations of available components having intersecting
    attributes (find component matches).

8.  The APP constructs a list of valid supply chain elements.

8a. If the supply chain for the order is complete, the APP displays the order options to the
    Customer along with soonest delivery time, total cost, and component attributes for
    each participant in the chain (e.g., participant reputation, material specifications,
    product dimensions, suitability for certification).

8b. Otherwise if one or more components is unavailable, the APP reprocesses the order with
    a new search for equivalent alternatives to the missing component(s) (back to step 5).

9a. If the supply chain is complete, the Customer receives the order options from the APP
    and filters, sorts, and inspects the presented solutions, selects a solution, and places
    the order.

    9a-1.  The order is delivered to the Customer and meets their expectations.(Favorable
    Outcome)
    9a-2.  The order is delivered to the Customer and does not meet their expectations.
    (Unfavorable Outcome)
    9a-3.  The order is not delivered to the Customer (Unfavorable Outcome).


9b. If no alternative supply chain can be found, the Customer is notified by the APP that the
    order cannot be completed at this time. (Unfavorable Outcome)


Assumptions/Abstractions:

The "Data for supply chain" event that is included in the APP and the Data Services/
Resources root represents asynchronous and continuous data for support to the
alternative supply chain construction.  The individual interactions involved here
are another level of refinement reserved for a separate MP model that can be elaborated
separately from this model which focuses on the Customer-APP interactions.

Postcondition:  The Customer receives 5,000 face shields (not shown in the model yet).

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SCHEMA Agile_Production_Platform_Customer_Interactions

ROOT Customer:      Log_into_APP
                    Input_a_need_for_5000_medical_face_shields

                    (   Receive_potential_solutions
                        Filter_sort_inspect_presented_solutions
                        Select_solution
                        Place_order

                      ( Receive_order
                        ( Order_meets_expectations  |

                            Order_does_not_meet_expectations )  |

                        Does_not_receive_order )    |

                            Unable_to_place_order );


ROOT APP:   {   Handle_User_Interactions,
                Manage_Supply_Chain_Options};

Handle_User_Interactions:   Authenticate_Customer_credentials
                            Prompt_Customer_for_need
                            Send_customer_order
                            (   Alternative_supply_chain_found
                                Display_potential_solutions_with_attributes
                                Place_orders_on_behalf_of_Customer   |

                                    Alternative_supply_chain_NOT_found
                                    Notify_customer_order_cannot_be_completed );

Manage_Supply_Chain_Options:    {   Identify_individual_components_of_needed_item
                                    Prepare_component_search_parameters
                                    Find_component_matches

                                    Construct_list_of_valid_supply_chains
                                    ( Complete_supply_chain_available Provide_list_to_user  |

                                        Complete_supply_chain_unavailable ),

                                    Data_for_supply_chain
                                };


COORDINATE $a: Log_into_APP                         FROM Customer,
           $b: Authenticate_Customer_credentials    FROM APP
    DO ADD $a PRECEDES $b ; OD;

COORDINATE $a: Prompt_Customer_for_need                     FROM APP,
           $b: Input_a_need_for_5000_medical_face_shields   FROM Customer
    DO ADD $a PRECEDES $b ; OD;

COORDINATE $a: Input_a_need_for_5000_medical_face_shields       FROM Customer,
           $b: Send_customer_order                              FROM APP
    DO ADD $a PRECEDES $b ; OD;

COORDINATE $a: Send_customer_order                              FROM APP,
           $b: Identify_individual_components_of_needed_item    FROM APP
    DO ADD $a PRECEDES $b ; OD;

COORDINATE $a: Provide_list_to_user                         FROM APP,
           $b: Display_potential_solutions_with_attributes  FROM APP
    DO ADD $a PRECEDES $b ; OD;

COORDINATE $a: Display_potential_solutions_with_attributes      FROM APP,
           $b: Receive_potential_solutions                      FROM Customer
    DO ADD $a PRECEDES $b ; OD;

COORDINATE $a: Place_order                          FROM Customer,
           $b: Place_orders_on_behalf_of_Customer   FROM APP
    DO ADD $a PRECEDES $b ; OD;

COORDINATE $a: Notify_customer_order_cannot_be_completed    FROM APP,
           $b: Unable_to_place_order                        FROM Customer
    DO ADD $a PRECEDES $b ; OD;


ROOT Data_Services_Resources:   Data_for_supply_chain;

/*  Abstracted out for now.  Will elaborate in a separate MP model.
                                {   [ Suppliers ],
                                    [ Shippers ],
                                    [ Manufacturers ],
                                    [ Distributers ],
                                    [ Design_Engineering ],
                                    [ Shipping_Distribution ],
                                    [ Customer_Services ],
                                    [ Market_Services ],
                                    [ Purchase_Order_Contract_Payment ]
                                };
```

```
*/

Data_Services_Resources, APP SHARE ALL Data_for_supply_chain;



/*----------------------- TABLES, CHARTS & DIAGRAMS ------------------------*/

COORDINATE $a: $$EVENT
DO
/* Customer durations, placeholder values only */
    IF $a IS Log_into_APP                                 THEN SET $a.duration AT LEAST 1; FI;
    IF $a IS Input_a_need_for_5000_medical_face_shields   THEN SET $a.duration AT LEAST 5; FI;
    IF $a IS Receive_potential_solutions                  THEN SET $a.duration AT LEAST 1; FI;
    IF $a IS Filter_sort_inspect_presented_solutions      THEN SET $a.duration AT LEAST 20; FI;
    IF $a IS Select_solution                              THEN SET $a.duration AT LEAST 1; FI;
    IF $a IS Place_order                                  THEN SET $a.duration AT LEAST 3; FI;
/* APP durations, placeholder values only */
    IF $a IS Authenticate_Customer_credentials            THEN SET $a.duration AT LEAST 1; FI;
    IF $a IS Prompt_Customer_for_need                     THEN SET $a.duration AT LEAST 1; FI;
    IF $a IS Send_customer_order                          THEN SET $a.duration AT LEAST 1; FI;
    IF $a IS Identify_individual_components_of_needed_item THEN SET $a.duration AT LEAST 5; FI;
    IF $a IS Prepare_component_search_parameters          THEN SET $a.duration AT LEAST 5; FI;
    IF $a IS Find_component_matches                       THEN SET $a.duration AT LEAST 60; FI;
    IF $a IS Construct_list_of_valid_supply_chains        THEN SET $a.duration AT LEAST 10; FI;
    IF $a IS Provide_list_to_user                         THEN SET $a.duration AT LEAST 1; FI;
    IF $a IS Display_potential_solutions_with_attributes  THEN SET $a.duration AT LEAST 1; FI;
    IF $a IS Place_orders_on_behalf_of_Customer           THEN SET $a.duration AT LEAST 1; FI;
OD;


/* Durations Table */

TABLE Durations_Table   {
                            TABS    string Event_name,
                                    number Start_time,
                                    number Duration_time;
                        };


/* Gantt Chart */

BAR CHART   Gantt_Chart { TITLE("Gantt Chart");
    FROM    Durations_Table;
    X_AXIS Event_name;
    ROTATE; /* to place the X_AXIS vertical */
};

COORDINATE $e: $$EVENT
    DO  /* add this event to the Table */
        Durations_Table         <|
            Event_name:     SAY($e),
            Start_time:     $e.start.smallest,
            Duration_time:  $e.duration.largest;
    OD;



/* Display on Output */

/*SHOW Durations_Table;
SHOW Gantt_Chart;
SHOW ACTIVITY DIAGRAM APP;*/

/*---------------------------------- QUESTIONS ------------------------------------*/

COORDINATE $x: Customer
            DO  ADD SAY("What additional interactions for the Customer may be needed "
                        "while the Customer is waiting for the order?")
                PRECEDES $x;
            OD;


/*---------------------------------- COMMENTS -------------------------------------*/

SAY("Partitioned the APP into user-facing " "and back end-facing functionality.");

COORDINATE $x: Data_for_supply_chain
            DO  ADD SAY("Represents asynchronous and continuous data "
                        "for support to the alternative supply chain construction.")
                PRECEDES $x;
            OD;

IF #Order_meets_expectations > 0 THEN
SAY("Favorable Outcome");
FI;

IF #Order_does_not_meet_expectations > 0 THEN
SAY("Unfavorable Outcome");
FI;

IF #Does_not_receive_order > 0 THEN
SAY("Unfavorable Outcome");
FI;

IF #Unable_to_place_order > 0 THEN
SAY("Unfavorable Outcome");
FI;
```

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APPENDIX B. SUPPLY CHAIN INTERACTION MODEL CODE

```
/* Author:  Josh Beaver
*/

SCHEMA APP_Supply_Chain_Interaction

ROOT Customer:
                            (*  submit_request_to_APP
                                receive_product
                            *);

ROOT Raw_Material_Supplier:
                            (*  receive_request_from_APP
                                (technical_expertise_to_make_product
                                    (material_on_hand
                                        (capacity_available
                                            make_material
                                                (test_or_inspection_conducted
                                                    (material_conforming        |
                                                    material_nonconforming      )   |
                                                test_or_inpsection_not_conducted    )
                                                ship_material                           |
                                        max_capacity                                    )   |
                                     material_out_of_stock                                  )   |
                                no_technical_expertise                                          )
                            *);


ROOT Component_Supplier:
                            (*  receive_request_from_APP
                                (technical_expertise_to_make_product
                                    (material_on_hand
                                        (capacity_available
                                            make_material
                                                (test_or_inspection_conducted
                                                    (material_conforming        |
                                                    material_nonconforming      )   |
                                                test_or_inpsection_not_conducted    )
                                                ship_material                           |
                                        max_capacity                                    )   |
                                     material_out_of_stock                                  )   |
                                no_technical_expertise                                          )
                            *);

ROOT Finished_Product_Supplier:
                            (*  receive_request_from_APP
                                (technical_expertise_to_make_product
                                    (material_on_hand
                                        (capacity_available
                                            make_material
                                                (test_or_inspection_conducted
                                                    (material_conforming        |
                                                    material_nonconforming      )   |
                                                test_or_inpsection_not_conducted    )
                                                ship_material                           |
                                        max_capacity                                    )   |
                                     material_out_of_stock                                  )   |
                                no_technical_expertise                                          )
                            *);

ROOT Agile_Production_Platform:
                            (*  receive_request_from_customer
                                submit_request_to_suppliers
                            *);

COORDINATE  $x: ship_material FROM Raw_Material_Supplier,
            $y: material_on_hand FROM Component_Supplier
        DO ADD $x PRECEDES $y; OD;
COORDINATE  $x: ship_material FROM Component_Supplier,
            $y: material_on_hand FROM Finished_Product_Supplier
        DO ADD $x PRECEDES $y; OD;
COORDINATE  $x: submit_request_to_APP FROM Customer,
            $y: receive_request_from_customer FROM Agile_Production_Platform
        DO ADD $x PRECEDES $y; OD;
/*COORDINATE    $x: ship_material FROM Finished_Product_Supplier,
            $y: receive_product FROM Customer
        DO ADD $x PRECEDES $y; OD;*/
COORDINATE  $x: submit_request_to_suppliers FROM Agile_Production_Platform,
            $y: receive_request_from_APP FROM Raw_Material_Supplier
        DO ADD $x PRECEDES $y; OD;
COORDINATE  $x: submit_request_to_suppliers FROM Agile_Production_Platform,
            $y: receive_request_from_APP FROM Component_Supplier
        DO ADD $x PRECEDES $y; OD;
COORDINATE  $x: submit_request_to_suppliers FROM Agile_Production_Platform,
            $y: receive_request_from_APP FROM Finished_Product_Supplier
        DO ADD $x PRECEDES $y; OD;
```

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APPENDIX C. MATRIX FOR TRACEABILITY FROM FIGURES TO MONTEREY PHOENIX CODE

Chapter IV Monterey Phoenix Models Matrix to Code				
Figure in Paper	File Name	MP Scope	Trace	
Figure 14	Agile Production Platform V4	2	4	*Earlier Revision of the Model no longer used.
Figure 15	Agile Production Platform V8	2	1	
Figure 16	Agile Production Platform V8	2	3	
Figure 17	Agile Production Platform V8	2	2	
Figure 19	APP_Supply_Chain_Interaction	1	2	
Figure 20	APP_Supply_Chain_Interaction	1	14	*Manual change made under customer root to "Does Not Receive Product" to correct the trace
Figure 21	APP_Supply_Chain_Interaction	1	36	

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