SCRL-Model for Human Space Flight Operations Enterprise Supply Chain

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Abstract — This paper will present a Supply Chain Readiness Level (SCRL) model that can be used to evaluate and configure adaptable and sustainable program and mission supply chains at an enterprise level. It will also show that using SCRL in conjunction with Technology Readiness Levels (TRLs), Manufacturing Readiness Levels (MRLs) and National Aeronautics Space Administrations' (NASA's) Project Lifecycle Process will provide a more complete means of developing and evaluating a robust sustainable supply chain that encompasses the entire product, system and mission lifecycle. In addition, it will be shown that by implementing the SCRL model, NASA can additionally define supplier requirements to enable effective supply chain management (SCM).

Developing and evaluating overall supply chain readiness for any product, system and mission lifecycle is critical for mission success.

Readiness levels are presently being used to evaluate the maturity of technology and manufacturing capability during development and deployment phases of products and systems. For example, TRLs are used to support the assessment of the maturity of a particular technology and compare maturity of different types of technologies. MRLs are designed to assess the maturity and risk of a given technology from a manufacturing perspective. In addition, when these measurement systems are used collectively they can offer a more comprehensive view of the maturity of the system.

While some aspects of the supply chain and supply chain planning are considered in these familiar metric systems, certain characteristics of an effective supply chain, when evaluated in more detail, will provide an improved insight into the readiness and risk throughout the supply chain. Therefore, a system that concentrates particularly on supply chain attributes is required to better assess enterprise supply chain readiness. [1,2]

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1. INTRODUCTION

Effective enterprise supply chain evaluation and development is a critical discipline in ensuring a sustainable mission lifecycle. A supply chain readiness level (SCRL) model is being developed to be utilized throughout the mission lifecycle in order to construct and sustain an adaptable and efficient enterprise supply chain.

UAHuntsville Office for Enterprise Innovation and Sustainability (OEIS) is supporting the Aerospace and Defense industries through applied research and solutions in Enterprise Supply Chain Development (ESCD) and Product Lifecycle Management (PLM). While supporting NASA's Constellation Supply Chain Manager in defining SCM requirements, UAHuntsville OEIS recognized the need for a model to objectively measure and configure efficient supply chains at an enterprise level.

This paper will define the need for an SCRL-model in supporting enterprise supply chain development. In addition the paper will describe the concept of the SCRL-model and define how it can be applied to NASA's program and mission supply chains. Additionally, the benefits of the model will be highlighted. Finally, the next steps to complete and validate the model will be outlined.

2. BACKGROUND: NEED FOR SUPPLY CHAIN READINESS

Enterprise Supply Chain Development

Supply Chain – A Supply Chain is simply defined in Wikipedia as a system of organizations, people, technology,

[1] 978-1-4244-3888-4/10/$25.00 ©2010 IEEE
[2] IEEEAC paper#1658, Version 1, Updated 2009:11:01

activities, information and resources involved in moving a product or service from supplier to customer[1]. Supply chains usually consist of multiple levels or tiers of entities that interact with one another to acquire resources, produce a product and deliver a product or service to a customer (Figure 1). In addition to the material or product flow, the information flow that supports the activities of the supply chain is also critical. Proper integration of information and material flow will have a significant influence on how effective a supply chain operates.

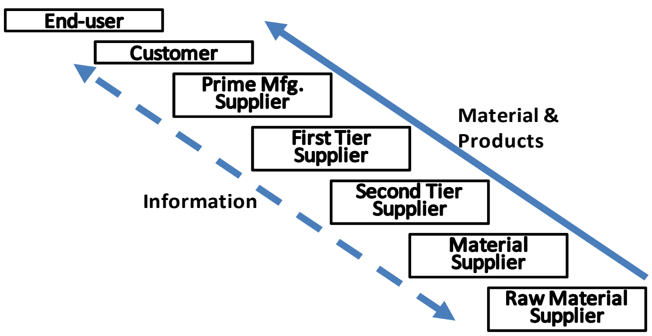

Figure 1 – Typical Supply Chain

Enterprise Supply Chain – An enterprise supply chain (ESC) view takes into account the supply chain from raw material to the final customer. However, rather than a sub-optimal approach where each entity only focuses on its own performance and its own objectives, the ESC view considers the impact of their performance on the global or end-to-end supply chain.

In addition, the ESC considers the total lifecycle of the product or system. This entire lifecycle is comprised of the design, development, testing and evaluation (DDT&E) phases, operational phases, sustainment phases and end-of-life phases of the program, system or mission.

Sometimes the supply chain may be thought of only in terms of those activities associated with logistics and supply base management. While these activities are critical enablers to an effective supply chain, the NASA ESC covers a much greater sphere. In the case of NASA Human Space Flight Operation, this enterprise view encompasses not only the vehicle development and sustainment, but also includes the overall mission objectives. In expanding this further, Galluzzi defines the Exploration Supply Chain as "the integration of NASA centers, facilities, third party enterprises and international partners, orbital entities, space locations, and space carriers that network/partner together to plan, execute, and enable an Exploration mission that will deliver an Exploration product (crew, supplies, data, information, knowledge, physical samples) and to provide the after delivery support, services, and returns that may be requested by the customer." [2]

Thus the NASA enterprise supply chain encompasses the agency and contractor activities and costs associated with DDT&E, production and delivery, operation and sustainment and all the resources required to support the vehicle launch, return, reclaim or disposal.

When considering the supply chain from an enterprise view (not simply limited to a logistics and supply base view) the supply chain is actually a complex network of interrelated entities that must work together to achieve mission success while meeting specific requirements (human safety, schedule, cost, etc.). In NASA's case, this complexity is amplified due to the multiple project offices and contractors, where a significant amount of the supply chain management activity is actually delegated to a contractor. To add to this complexity, often the requirements for supply chain entities my seemingly compete with one another. Because of this complexity and the human safety implications associated with human space flight, effective enterprise supply chain management is critical to mission success.

Supply Chain Management – Supply chain management (SCM) has been defined as a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and the right time, in order to minimize system wide cost while satisfying service level requirements[3]. SCM of the enterprise supply chain considers the cost and mission success of the entire enterprise, not necessarily just an individual entity or organization. A 2003 Deloitte and Touche study noted that "only 7% of companies today are effectively managing their supply chain. However, these companies are 73% more profitable than other manufacturers."[4] In commercial industries, where the supply chains are market driven and typically designed for higher volume product, many common SCM practices have been successfully implemented to improve supply chain performance. These proven SCM practices and technologies can be introduced and successfully integrated into the low-volume, schedule-driven human space flight enterprise supply chains. For example, Galluzzi and others have noted that utilizing proven SCM tools is possible in aerospace by fostering a "risk-shared endeavor between customer and contractor, that utilizes an integrated and cost effective supply chain through collaborative demand planning, Component Supply Management (CSM), product standardization, rapid mobilization of consolidated manufacturing sources and SCM simulation and modeling."[5]

Supply Chain Development Opportunities –A number of supply chain related problems are plaguing the aerospace industry. In evaluating supply chain costs and performance, Sullivan summarizes a few of these problems:

- Long and growing lead times (raw material being the driver)

- Few long term contracts exist in the supply chain
- Essentially no visibility of demand in the supply chain
- Continuous improvement programs are focused on localized manufacturing processes[6]

Such supply chain concerns can result in schedule delays, out of stock conditions and increased costs in attempts to overcome the delays and resolve inventory issues. For example, due to limited visibility and little collaboration in the supply chain, changes in the rate of material flow may not be efficiently recognized and communicated before adversely impacting supply chain performance. Consider that if there is a drastic change in commodity prices, raw material flow into the supply chain could be affected. Even after this problem is discovered, however, contracts and supplier agreements may not be flexible enough to be able to react to the price fluctuations. The supply chain should have the visibility into these potential raw material risks and become more adaptable by integrating built-in flexibility to address such possible price and flow variation.

Since it can be costly to change existing contracts and practices to address these issues in an existing supply chain, a more economical approach would be to construct an agile and sustainable supply chain during the program development phases. Applying SCM disciplines early in the development phase can mitigate these concerns. Specific to NASA, Galluzzi notes, "applying these disciplines is especially crucial during the early design, development, test and engineering (DDT&E) phase of a new program. Upwards of 70 to 80% of the operational recurring costs, which include 90% of the indirect processing costs associated with Launch and Landing core activities, are influenced as a result of this initial phase of the product lifecycle." [7]

What is needed is a method to evaluate, and configure adaptable and sustainable program and mission supply chains that considers the enterprise view of the supply chain and incorporates proven SCM practices and technologies.

Supply Chain Key Performance Indicators – One effective critical SCM practice that should be highlighted is the need for key performance indicators that measure the performance of the enterprise supply chain and promote continuous improvement.

The Supply Chain Council has developed a Supply Chain Operations Reference (SCOR) model that includes a set of standard supply chain performance metrics. The SCOR-model "provides a unique framework that links business process, metrics, best practices and technology features into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities."[8] The SCOR-model allows for any supply chain to be defined in a standard activity-based structure that can be evaluated based on a standard set of metrics. In addition, for all of these standard activities, the Supply Chain Council has defined best practices for improving performance of the Supply Chain as it relates to the defined activities.

A standard model and standard set of performance metrics is critical for a complex enterprise supply chain to effectively measure performance. Further, the metrics required to measure the ESC mission performance of the entire lifecycle need to be defined during the early phases of mission development. In addition, the information structure and data requirements to support these metrics need to be designed and implemented as the programs and systems are being developed so that the metrics will be effectively populated throughout the total lifecycle.

Systems Engineering and Readiness Levels

Readiness Levels – Readiness level models and assessments have been developed to evaluate technology development and manufacturing capability. Both NASA and the Department of Defense (DoD) have utilized these tools as part of project and acquisition lifecycle processes.

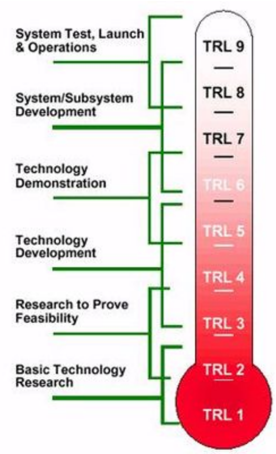

Figure 2: Technology Readiness Levels[11]

Technology Readiness Levels – Technology Readiness Levels (TRL) "are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology"[9]. The DoD defines the Technology Readiness Assessment (TRA) as "a formal, systematic, metrics based process and accompanying report that assesses the maturity of critical hardware and software technologies to be used in systems"[10]. In essence, TRL describes the "state of the art" of a given technology as it relates to a given system, subsystem, or component. Utilizing a prescribed assessment process, a TRL level (Figure 2) is defined in order to understand the maturity of a technology so as to define what is needed to develop that technology to the required level for mission success.

Manufacturing Readiness Levels – Manufacturing Readiness Levels (MRL) have been developed to assess the maturity and risk of a given technology from a manufacturing perspective. The DoD Manufacturing Readiness Assessment (MRA) Handbook defines manufacturing readiness as "the ability to harness the manufacturing, production, quality assurance, and industrial functions to achieve an operational capability that satisfies mission needs."[12] The MRA Handbook accurately asserts that "manufacturing readiness and producibility are as important to the successful development of a system as those of the readiness and capabilities of the technologies intended for the system design." [12]

Engineering Manufacturing Readiness Levels – Missile Defense Agency (MDA) has used Engineering Manufacturing Readiness Levels (EMRL) which have similarities to MRLs in their goal of understanding manufacturing risk and maturity, but utilize (the) design and development process mapped to a single sheet of questions to determine these levels. Within the EMRL assessment is a requirement for a certain level of technology maturity[13].

Program / Acquisition Lifecycle Framework – Both TRLs and MRLs are used in the program and system development. Figure 3 indicates the nominal relationship between specific MRLs and the Acquisition Lifecycle Framework as well as the nominal relationship between MRLs and TRLs. The intent in defining this relationship is to define and mitigate manufacturing and technology risks before transitioning to the next phase in the development process.

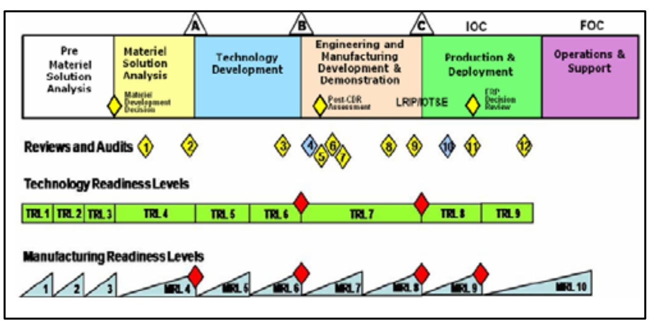

Figure 3: Defense Acquisition Life Cycle Framework and relationship to TRL and MRL[12]

Supply Chain Readiness Levels – Technology and manufacturing readiness is critical to program development. Since the supply chain encompasses both, the technologies and manufacturing activities, supply chain readiness is equally important to develop the supply chain for that program. Furthermore, it can be noted that just as the technologies and manufacturing capabilities are being evaluated through the development process, a similar tool to measure supply chain readiness could be used to effectively develop the enterprise program and mission supply chain.

It is proposed that a SCRL-model can be used to assess the supply chain readiness and maturity of an enterprise supply chain. While the model can be used to evaluate an existing supply chain, the full benefit would be realized when the SCRL-model is used in conjunction with the project and acquisition lifecycle processes in order to construct an efficient, healthy, reliable and flexible supply chain for the program being developed.

3. SCRL-MODEL

SCRL-model Purpose – The SCRL-model will provide a means of objectively measuring total supply chain adaptability and sustainability. The model can be used to construct developing supply chains or evaluate those that are already in operation. In addition, the model should contain some objective criteria and yet be flexible enough to be utilized across multiple programs within NASA, on program supply chains in other agencies or across multiple agencies (e.g. DoD).

SCRL Model Approach – Figure 4 describes the approach taken in developing the SCRL-model.

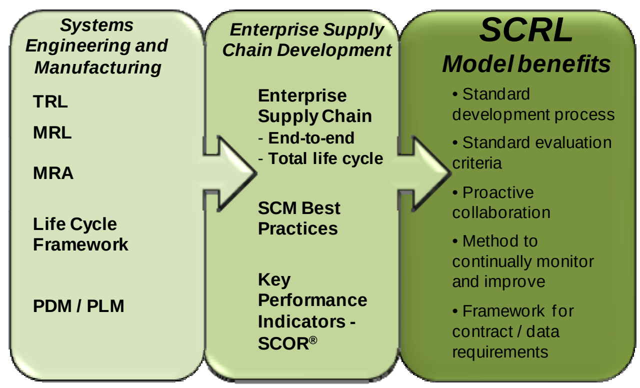

Figure 4: SCRL Development

The idea is to merge existing systems engineering methodology with enterprise SCM best practices and technologies. The primary aspects of the Systems Engineer approach considered are:

- TRL: Technology Readiness Levels
- MRL: Manufacturing Readiness Levels
- MRA: Manufacturing Readiness Assessment
- Life Cycle Framework: NASA Systems Engineering Project Life Cycle; Defense Acquisition Life Cycle Framework
- PLM/PDM: Existing Product Lifecycle Management & Product Data Management policies

A few critical aspects of the enterprise supply chain management and development that are considered include:

- End-to-end view of the supply chain, from raw material to end customer.
- Total mission life cycle view including supportability phase
- Key standard performance metrics and best practices (SCOR)

Each of these aspects of enterprise supply chain management and how they relate to supply chain development are described in detail above.

SCRL-model Description – The SCRL-model will be constructed with increasing levels of maturity or development. As shown in Figure 5 below, the SCRL will incrementally change from lower to higher levels. It should be noted that the SCRL numbers 1-10 are notional, as the final number of levels is still being defined.

The increasing supply chain readiness levels represent the developing supply chain as it transitions from an immature supply chain to a mature supply chain. At the lower SCRL the supply chain risks have not been identified and mitigated, thus resulting in higher enterprise supply chain costs. As the SCRL increases to the highest levels, the risks are identified and mitigated and the supply chain is operating at the lowest enterprise cost while still meeting defined operating requirements.

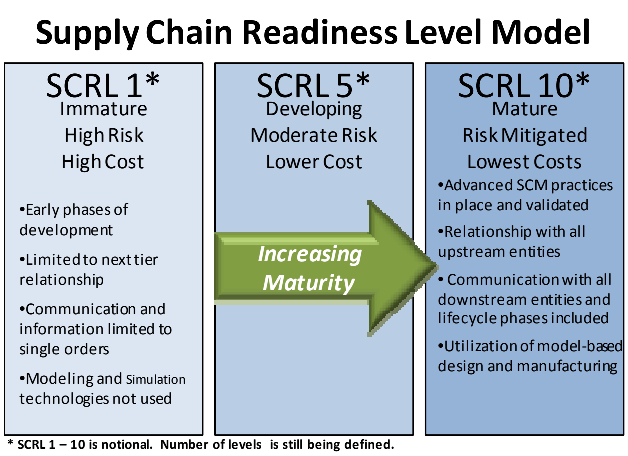

Figure 5 – Supply Chain Readiness Level Model

The Extended Supply Chain - From an enterprise view, the mission and program supply chain will consist of particular subsystems at lower levels in the supply chain. The supply chains for the individual subsystems can be evaluated and their SCRL defined individually. As shown in Figure 6, the expectation is that the SCRL will increase with the depth of the supply chain level being assessed. Another way of stating this is that the overall enterprise supply chain SCRL can only be as high as the lowest SCRL of any subsystem supply chain. This approach ensures that from a systems perspective the supply chain performance for each subsystem is increasing as the overall system is being developed.

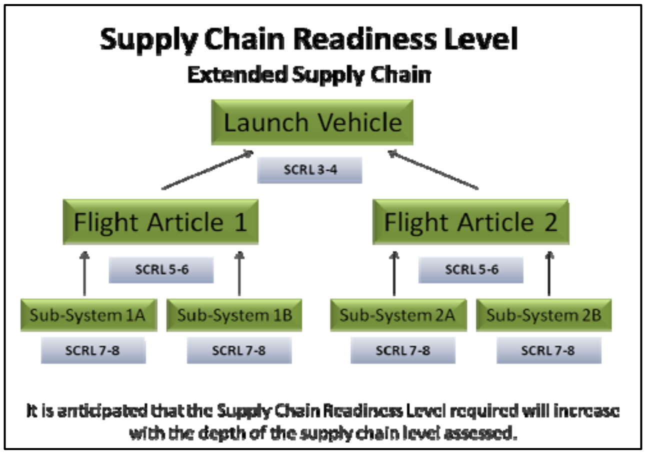

Figure 6: Supply Chain Readiness Levels showing increasing SCRL with depth in supply chain

Supply Chain Characteristics – The SCRL-model will describe the supply chain by defining supply chain characteristics and SCM practices that have been proven to be effective both in the private and public sectors. For each supply chain characteristic, condition or practice, the SCRL will increase as the supply chain is developed and the defined practices are established and validated.

Example SCRL Characteristic: Visibility – Consider the characteristic of visibility. Visibility, as it relates to the enterprise supply chain, can be defined as the ability to see "who" (supply chain entities) and "what" (products, materials or services provided) at varying levels in the supply chain. For SCRL 1, the "who and what" may only be visible at the direct customer and supplier level (one level up and down the supply chain). At SCRL 10 however, visibility is extended to all upstream supply chain entities and all parts or components they produce are known. Obviously this supply chain visibility is critical to other characteristics and disciplines defined in the model (e.g. risk identification and mitigation, strategic inventory placement, etc.).

Relationship to Project and Acquisition Lifecycle Process – As stated above the intent is to merge the systems engineering project development process with enterprise supply chain development best practices and metrics. To accomplish this, SCRLs will be overlaid to the existing project and acquisition lifecycle processes thus linking the SCRL (and associated disciplines and practices) to the lifecycle processes through relevant reviews and decision points. This is a critical component of the SCRL-model.

Generally speaking, as soon as a product or technology is being conceptualized, the supply chain is being conceptualized simultaneously. For example, if a particular material is selected, the supply base for that material is instantly linked to the chain. Logically, as the technology and manufacturing capabilities are being assessed and measured through the development process, the supply chain should be evaluated and assessed concurrently. By aligning the SCRL-model to the project and acquisition lifecycle processes, existing gates and reviews can be used to trigger an assessment of the supply chain readiness.

An effective supply chain is obviously dependent on the maturity of the technologies, manufacturing capabilities and integrated systems to which it is associated. For that reason the SCRL will be correlated with MRL and TRL standards which would be expanded to encompass the total supply chain.

Additionally, the model will allow for agency specific requirements related to the supply chain. In this way the model can be used within an agency on multiple programs and ensure agency-specific supply chain requirements are addressed in the development process. In addition, since the agency-specific requirements are adaptable, the model itself is flexible enough to be used by and across multiple agencies.

By correlating the SCRL-model to the project lifecycle process, SCM practices that may impact the supply chain at different phases of the program and mission lifecycle are being defined during supply chain development. For example, a common practice in enhancing ESC performance is strategic inventory management within the global supply chain. As the requirements for the ESC are being established (e.g. spares availability), inventory levels can be established such that the availability requirements can be achieved at the lowest costs to the overall supply chain. This risk sharing technique, requires that supply chain partners collaborate (share information) early in order to establish the agreed upon levels. While the benefit of this practice may not be realized until the operational phase of the program, the requirements, policies and contracts can be established in the development phase in order to accurately define future service levels and planned costs.

Model Characteristics Sections and Assessment – The SCRL-model utilizes proven SCM disciplines and the related supply chain characteristic to assess and measure the supply chain performance.

The SCRL Characteristic Table in Figure 7 notionally describes the SCRL supply chain characteristics. For each characteristic, the evaluation criteria for the lowest and highest level of SCRL are defined here. The intent is to evaluate the supply chain using defined assessment questions and assign an SCRL number for each characteristic based on the assessment criteria and demonstrated results for that section. A SCRL would be assigned to each section according to the results of the assessment. The overall SCRL for the supply chain being evaluated will be determined by the minimum SCRL assigned to the individual SCRL assessment section. The assessment results could then be used to identify the specific supply chain characteristics and practices that should be addressed to increase the SCRL and reduce the risk and cost before moving to the next development phase.

Performance Metrics - Strategic supply chain metrics will be defined and associated to each characteristic. Many of the metrics defined in the model will be from the SCOR-model. As described above, the SCOR-model has defined standard supply chain metrics that are associated with SCM best practices. These metrics are structured into ten high-level strategic metrics which are comprised of a total of thirty diagnostic metrics. The model also contains a list and description of over five hundred additional diagnostic metrics that are utilized in supply chain management. The SCRL-model will incorporate only a few of the strategic and diagnostic metrics that correlate to the supply chain characteristics defined in the model.

4. BENEFITS OF SCRL-MODEL

Standard Assessment and Construction Model – The SCRL-model will enable any Supply Chain to be assessed based on proven characteristics required for a flexible, agile, viable and sustainable Supply Chain. The phased model enables the systems engineering methodology of technology and manufacturing capability to be aligned with the enterprise supply chain development and acquisition strategies. In using SCRL-model, all projects, offices and sub contractors are concurrently addressing SCM issues in the same manner at the same rate. Additionally, by defining the Supply Chain requirements, risk mitigation can begin in the earliest phases and accurate lifecycle costs can be assessed and controlled.

Ultimately the resultant supply chain that is developed to a high SCRL will be in a position to effectively meet the supply chain requirements as it is being developed, rather than the supply chain partners (and in NASA's case, the customer) incurring incremental cost to address problems later in the lifecycle.

Proactive Collaboration – As described above, when SCM practices are defined during the development phases, entities of the supply chain must develop collaborative structures and relationships early on. This relationship will create an environment of improved visibility, efficient information flow and risk sharing throughout the total mission lifecycle. –Also consider that as the lifecycle of the supply chain progresses, demand and material flow may vary. As a result, the supply chain policies (including NASA policies and contractor agreements) should be defined early on and be flexible enough to adapt to these changes without unplanned and exorbitant incremental costs to the global supply chain. SCRL will encourage that these practices be in place during the supply chain development process.

SCRL Model Characteristic Table

SCRL		SCRL 1	SCRL 10
Characteristic	**Description**	⟵	⟶
Inventory	**Placement of inventory throughout the supply chain**	Inventory levels are not known throughout the supply chain. Inventory is not optimized even at the local level.	Inventory is strategically placed throughout the supply chain to minimize total supply chain inventory costs while still satisfying the readiness demands of the system
Supplier Consolidation	**Supplier consolidation program (no redundant suppliers for non-critical items)**	Suppliers throughout the supply chain are not visible beyond the next-level customer and no consolidation efforts in place.	Program in place to regularly monitor and reduce redundancy of suppliers of non-critical items to standardize products, quality and cost.
Supplier/Customer Relationships	**Working relationships between suppliers and customers at varying levels of the supply chain**	Supplier/customer relationship is defined only by the terms and conditions of a contract or purchase order.	Supplier/customer relationships allow for teamwork to improve supply chain. Multi-organization improvement events are ongoing.
Commodity Price Adaptability	**Impact of variations in the price of commodities (steel, energy, etc.)**	Commodity prices not monitored.	Long-term contracts in place that provide flexibility for commodity price fluctuations.
Visibility	**Ability to see who and what at varying levels of the supply chain**	Only direct customers and suppliers are known	All upstream supply chain entities and the parts they produce are known
Collaboration	**Flow of information up and down the supply chain**	Only information necessary for placing and processing orders is exchanged between supply chain entities	Collaborative system is utilized to provide real-time demand and other pertinent information to the lowest level of the supply chain
Lifecycle Awareness	**Visibility and awareness throughout the supply chain of the current lifecycle phase**	Activities and visibility are related only to current and known orders	Health of downstream supply chain entities and lifecycle phase are known
Modeling and Simulation Technology	**Application of modeling and simulation to improve supply chain performance**	Modeling and simulation technologies are not used for any supply chain activities	Modeling and simulation technologies utilized to provide what-if analyses of supply chain risks
Performance Measurement	**Use of metrics to evaluate and improve supply chain performance**	Supply chain performance is not measured	SCOR metrics and best practices utilized throughout supply chain to provide standard measure of performance
Risk Management	**Management of risk (including obsolescence, sole-sourcing and counterfeit parts)**	Risks of obsolescence, sole-sourcing and counterfeit parts are not known	Monitoring, assessment and contingency plans in place to address risks of obsolescence, sole-sourcing and counterfeit parts
Criticality Focus	**Focus level on critical items and suppliers**	Critical items and suppliers are not known	Critical items and suppliers are identified, closely monitored and contingency plans in place to ensure part availability
Sustainability	**Long-term viability of the industrial base**	Suppliers are not known beyond next level in the supply chain	Supply chain is managed with a lifecycle approach. Industrial base financial stability is regularly monitored and action is taken to ensure sustainability between programs
Manufacturing Readiness	**Monitoring the manufacturing readiness of the supply chain**	Manufacturing readiness is not measured	MRL of all levels of the supply chain are regularly assessed and maintained at a MRL 10
Technology Readiness	**Monitoring the technology readiness of the supply chain**	Technology readiness is not measured	TRL of all levels of the supply chain are regularly assessed and maintained at a TRL 10
Sub-Tier Management	**Assurance that all levels of the supply chain adhere to SCRL standards**	There are no supply chain management expectations of the next level in the supply chain	SCRL of next level of supply chain is regularly assessed and maintained at a SCRL 10

Figure 7: SCRL Model Characteristics Table

Continually Monitor and Improve – As noted above, utilizing the SCRL-model provides a framework to identify and analyze problems. By highlighting these characteristics of the supply chain, performance gaps can be identified and addressed. Previously such conditions may be been overlooked as "business as usual" or too costly to address. However, by using the SCRL-model, these issues can be addressed during the development process before there is an actual problem that impacts mission success.

Additionally as conditions and entities change during the program lifecycle the ESC can be continually monitored and evaluated using the SCRL-model assessment.

Framework for Contracts and Data Requirements – As the mission ESC is being developed and the SCM practices are established, the policies and contracts can be structured to support the efficient operation of the mission supply chain. In addition the data requirements to operate and measure the performance of the ESC will be defined as well

5. APPROACH AND NEXT STEPS

The UAHuntsville OEIS began developing the SCRL while supporting the Constellation Supply Chain Manager in developing contract requirements to support effective supply chain development and management within NASA. During the work on that project, UAHuntsville recognized that a supply chain readiness level model enfolded into the existing project lifecycle process would be an effective tool to guide supply chain construction and develop contract language and data requirements to foster efficient SCM practices.

To date the general concept of the model and notional supply chain characteristics have been defined. The next steps for UAHuntsville OEIS team are as follows:

(1) Finalize definition of critical characteristics of a supply chain

(2) Finalize the characteristic conditions that must be validated for each SCRL number.

(3) For each characteristic, define metrics that best describe the performance of that characteristic of the supply chain.

(4) Peer review the model to refine and finalize.

(5) Develop SCRL Assessment list of questions that can be used to assess SCRL maturity

(6) Validate the model by using SCRL Assessment to evaluate an existing supply chains for both NASA and DoD.

(7) Further validation could be done by assessing multiple supply chains at various levels of maturity and measure the performance (metrics and costs) to validate correlation SCRL maturity to the performance metrics.

(8) Align the SCRL phased progressions to project and acquisition lifecycle process and the phased progressions of the MRLs, TRLs and EMRLs

Modeling and Simulation

UAHuntsville would like to apply SCRL to existing supply chain simulation models and/or develop additional supply chain models in order to additionally validate the SCRL-model. Simulation would allow for manipulating the SC model (thus altering the SCRL) and measuring the impact to the enterprise supply chain. This can be accomplished with full supply chain model or by using models that focus on specific characteristics (e.g. strategic inventory placement).

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Brian Tucker *Brian Tucker is a Research Scientist in the Office for Enterprise Innovation and Sustainability at the University of Alabama in Huntsville where he provides supply chain support for both private and government organizations. Mr. Tucker has over 16 years of engineering and management experience in various industries including metals, appliance, automotive, forest products, aerospace and defense. His work experience includes roles as Supply Chain Operations Lead, Supply Chain Continuous Improvement Engineer, Lean Trainer/Facilitator, Production Manager, Engineering Services Manager, Manufacturing Engineer and Quality Engineer.*

Mr. Tucker has a Bachelors Degree in Industrial and Systems Engineering and is currently pursuing a Master's degree in Industrial Engineering with a major in Manufacturing Systems from the University of Alabama in Huntsville. He has trained and assisted numerous personnel at all levels of various organizations in continuous improvement and enterprise value stream mapping. Additionally, he is an ISO 9000 Auditor and has direct experience with the DuPont STOP safety program, ISO 14001, TS16949 and specific Six Sigma and lean concepts, such as enterprise value stream mapping, 5S, SMED, TPM and Lean Office.

Joe Paxton *is a Principal Research Scientist in the Office for Enterprise Innovation and Sustainability at the University of Alabama in Huntsville. He has over 15 years experience in engineering and engineering management in private, public and state and federal government organizations. His work experience includes roles as Sr. Mechanical Engineer, Project Coordinator, Research Scientist, Strategic Services Manager, Area Manager and Supply Chain Manager.*

Mr. Paxton has experience in training and implementing lean manufacturing, as well as optimizing supply chains. He has trained personnel, facilitated continuous improvement activities and coached executives in numerous industries, including automotive, electronics, medical, industrial equipment, forest products, and aerospace/defense. His most recent experience involves mapping and optimizing supply chains for the NASA Ares launch vehicle and various U.S. Army weapon systems, as well as improving manufacturing operations and demand planning processes for a major commercial/military aerospace supplier.

Mr. Paxton is a NIST certified trainer in Principles of Lean Manufacturing, 5S, Quick Changeover, Kanban/Pull Systems, Total Productive Maintenance and Value Stream Mapping. He holds a Bachelor's degree in Mechanical Engineering and a Master's degree in Industrial Engineering with a major in Manufacturing Systems. He also has a Six Sigma Green Belt and has received numerous commendations from customers, both commercial and government.