Startup Operations and Supply Chain road guide proposal, based on Robotics Cluster Case Studies

by

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Abstract

Concerted efforts are being pursued by governments and economic institutions to promote the generation of startups, and copious documentation has been produced as guides for these emerging companies. However, little has been written on, e.g., the Operations and Supply Chain needs for Hardware Startups, and the development strategy of the required skills to build flexibility during the initial phases of startup development.

This work proposes an initial road guide framework for hardware startups, resulting from the experiences of successful companies within the Robotics Cluster present in Massachusetts (either new ventures or spinoffs from existing companies). System Dynamics methodology is then used to capture causal loops, and to characterize the policies which would enable New Venture growth, so as to analyze the Supply Chain/Operations conditions for Hardware Startup Success.

The work is presented in four main sections. The first section contains a bibliographic research to characterize the present conditions of Hardware Startups with special emphasis on the Massachusetts Robotics Cluster, providing an overview of the available resources for startups in terms of their skills development and especially with regard to their Operations/Supply Chain Skills development. A second section considered the directed interview of executives at existing robotics startups (Artaic LLC, Kiva Systems, Rethink Robotics and Boston Engineering) to obtain information regarding their strategic decisions in specific aspects of their Supply Chain and Operations. These interviews are reflected as case studies of these companies. The third phase is reflected as a proposal for a System Dynamics model, based on previous work in the area and complemented by aspects identified as relevant from the interviews. Lastly, the conclusions of this work will attempt to gather the main learnings from the analyzed cases, in terms of Operations/Supply Chain Skills development, laying down some directing guidelines for future Hardware Startup ventures.

Thesis Supervisor: Charles Fine
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The search for knowledge is never a lonesome activity. The work here presented is the fruit of my interaction with several people who selflessly shared their experience and insights. Professor Charles Fine led the way with his Operations for Entrepreneurs, setting a framework which delightfully aligned with my intentions to discover a bit more on how companies were started and their skills developed within the robotics cluster present in Massachusetts. His open feedback and guidance have a set a standard on how I will in future guide others who come to me for such a guide.

It is from the group of robotics entrepreneurs where I also hold a great debt of gratitude, for the willingness to share and reflect upon the experiences they have gathered throughout their company history. My sincere thanks to Ted Acworth from Artaic, Jim Daly from Rethink Robotics and Mick Mountz from KIVA for the interesting interviews which they allow me to carry out, as they found a time to listen to this inquisitive student within their busy schedules.

The final interviews were indeed a culmination of previous research and contacts, facilitators which are crucial to the success of this research. My particular thanks to Pete Wurman from KIVA and Matt Beane at MIT.

At the base of every activity in my life is my family. Thank you Marcela for the ongoing support in so many levels, which make this successful adventure at MIT possible, and for always reminding me that I will achieve anything on which I set my eyes.

Daniel Sepulveda

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1 Objectives of this work

Given the exceptional role Startups have in any economy, and the present gap in the understanding of how Hardware Startups adjust internally within their business context, it is sensible to a seek greater understanding of the systemic forces that exist and interact within these organizations (particularly during their period of growth and co-evolution of Organization vs. Contextual Requirements) with the aim of identifying adequate policy levers, acting either upon the company or upon the industry, that will optimize this coevolution process.

The objectives of this work can therefore be identified as:

- Gather the Experience of Hardware Startup Companies through Interviews with relevant members of their staff, reflecting this experience as Case studies for each of these companies,
- Propose a System Dynamics Model to account for the Supply Chain & Operations Skills Development in Hardware Startups,
- Contrast this System Dynamics Model with the evidence gathered through the Case Studies, and
- Produce a Hardware Startup Guideline Framework proposal, based on the interview-gathered Startup experience, and the subsequent System Dynamics Model

The work is presented in four main sections. The first section contains a bibliographic research to characterize the present conditions of Hardware Startups (Chapter 2) with special emphasis on the Massachusetts Robotics Cluster (Chapter 3), providing an overview of the available resources for startups in terms of their skills development and especially with regard to their Operations/Supply Chain Skills development.

A second section considered the directed interview (Chapter 4) of executives at existing robotics startups (Artaic LLC, Kiva Systems and Rethink Robotics) to obtain information regarding their strategic decisions in specific aspects of their Supply Chain and Operations. These interviews are reflected as case studies of these companies (Chapter 5) with an emphasis on their Supply Chain Skills acquisition and development. These interviews are analyzed and the findings structured (Chapter 6).

The third phase is reflected as a proposal for a System Dynamics model (Chapter 7), based on previous work in the area and complemented by aspects identified as relevant from the interviews (Chapter 8), to subsequently characterize the policies which will enable New Hardware-related Venture growth.

This work will end with a contribution towards a Road Guide Framework for Hardware Startups (Chapter 9), resulting from the interviewed companies' know-how, and its subsequent analysis.

2 Startups in the economy

Startups are exceptionally relevant players in the economy of any country. This was first argued explicitly by Joseph Schumpeter in 1934. Entrepreneurs were described as the "agents of creative destruction" who introduce change in a landscape of established incumbents, by challenging the incumbent's positions. New ventures have thereafter been seen as sources of job creation, facilitators of technological transfer from research to industry, and boosters of productivity (Ács, Autio, & Szerb, 2014).

Although it is a widely held belief that jobs are created (and destroyed) by companies of all sizes, studies have shown that in fact, net job growth occurs in the US mainly through startups. A study performed with information from the Business Dynamics Statistics (a U.S. government dataset compiled by the U.S. Census Bureau) for the years 1977 to 2005, revealed that existing firms were net job destroyers, eliminating around 1 million jobs per year from the economy, while new firms added an average of 3 million jobs per year to the economy. Additionally, 1 year old firms created around 3 times the number of jobs created by firms of around 10 years of age (Kane, 2010). Finally, the National Bureau of Economic Research has shown that, when controlled by company age, there is "no systematic relationship" between the size of a firm, and the growth in Jobs for which this firm is accountable (Harrison, 2013). High Tech startups[1] between 1 and 5 years of age created 16,700 new jobs in the U.S., while other businesses between 1 and 5 years of age in the private sector lost 513,000 jobs overall (Dwyer, 2013).

Studies have also shown that fewer than half of the positions created by startups are actually still in existence after five years, and net employment growth declines sharply as companies grow older. This leads to the conclusion that the stability offered by established companies is greater than the stability

[1] High Tech Startups, as defined by the Kauffman Foundation Report, are companies whose employees work mainly in engineering, math, science and technology field-related activities.

available at a startup venture. Also, the positions within startups are less lucrative, since startup employees earn an average of 70% the salaries of people employed by established companies (Dwyer, 2013).

Startups are defined as companies that are in their first stages of operation, managed by a founding team who own the business idea and have undertaken the financing of this organization's activities during the development of a product of service for which they believe there is a demand. Startups have also been defined as companies working to solve a problem for which the solution is not obvious and success is not guaranteed (Robhemed, 2013). Some authors identify startups as organizations that are formed to search for a repeatable and scalable business model, with variable early goals (as defined by the early investors, e.g., revenue, profits, users). These organizations typically consider an iterative hypothesis-testing process which leads to repetitive business model adjustments (Blank, 2010).

There are no defined rules through which Startups can be identified, but there are a series of symptoms which may indicate a company ceased to be a Startup, for example, being acquired by a larger company, having more than one location for their operations, having revenues of over US$ 20 million per year, having over 80 employees, having more than 5 people on the board, or having founders who have personally sold shares.

A definitive characteristic of a startup is its potential for quick and exponential growth, and is therefore an organization that should consider capabilities for rapid implementation of activities' scaling up at a certain point in its operation. Moreover, growth unconstrained from geographical location is an important differentiator of Startups from Small Businesses[2].

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[2] Arguably, a small restaurant would through this definition, not be considered as a Startup.

Notwithstanding their crucial role in the economy, Startups have a particularly high failure rate. The problem of increased complexity in operations and associated scaling requirements, and the failure of businesses to timely and diligently address these needs, has been pointed out as one of the major causes of failure within Startups, characterized by a plateau that is reached by businesses. About 50% of Startups fail within 3 years of having been founded, and 94% will never break the US$94 million revenue mark (Nisen, 2013).

In a recent study at the Small Business Development Center at the University of Tennessee, a survey gathered information on the reason why new businesses had failed. It showed that over 40% of the analyzed cases failed due to a Supply Chain related issue e.g., did not perform planning in their supply chain activities, were not able to manage their business expansion, did not make an adequate management of suppliers or failed to manage Inventory effectively (U.Tennessee, 2014).

Some argue that a startup is in fact a cultural state in the operational condition of an organization characterized by a dynamic culture reflected as flexible roles, constant evaluation of improvements or changes, and subsequent rapid adaptation of activities. Through this definition, a company could in theory remain a Startup for much longer.

2.1 Relevance of Hardware Startups

Hardware Startups are a special kind of venture, engaged with the creation, manufacture and distribution of physical products, normally involving differentiation through technology, and fueled by development in HCI (Human-Computer Interaction) technologies, as well as the DIY (Do-It-Yourself) Movement (Lindtner, Hertz, & Dourish, 2014).

Some authors have indicated the culture of "building things" as the way for future economic recovery through the relationships that are formed by having a project with some sunk costs involved, in contrast with what might be a service-related startup (Yang, 2014).

It is also relevant to point out that an industry is being built around Hardware startups, with related companies providing services to streamline the idea-to-market process. These include Business Consultants, Contract Manufacturers, Macro Tasking, Micro Tasking and specialized Hardware Startup Team Sourcing companies.

Business Consultant are beginning to approach Hardware Startups at increasingly earlier stages in their development, offering design and engineering support. An example of this is Dragon Innovation[3], a Massachusetts-based company started by hardware industry veterans which provide guidance to newly formed companies, mainly in the electronics industry, specializing in management processes for the complete idea-to-market cycle, leveraging Maker Spaces, and achieving an optimum access to Crowd Funding Tools.

Contracts Manufacturers are considering partnering with Hardware Startups as a way of diversifying risk through a larger pool of customers and the offer of additional services such as design and engineering for production, as well as benefiting from the small production batches initially required by these startups, and desirable by these contractors to fill in gaps in production schedule due to demand variation from other larger customers, especially in the stages when these ventures are turning to mass production (Comstock, 2014).

Maker Spaces, also known as Fablabs, Hackerspaces, Hackspaces or DIY Spaces, are a trend that started in Europe around 1995, mainly by programmers, who shared a common creative space, and is a trend that

[3] https://www.dragoninnovation.com/

arrived to the U.S. in mid-2000's through private business ventures, and spinoffs from University Labs. These places gradually added design/manufacturing capabilities, first for electronic circuits and later for physical prototyping, to eventually include a diversity of classes as well as access to manufacturing tools through a membership quota. These places therefore allow for access to manufacturing equipment at a fraction of the cost involved in buying these tools and provide a place for the implementation of ideas (Cavalcanti, 2013; Kroski, 2013). Examples of these Makerspaces include Techshop[4] (2006), FabLabs[5] born out of MIT´s Media Lab (2005), Artisan's Asylum[6], MakerWorks[7], Columbus Idea Foundry[8], Noisebridge[9] and HacDC[10].

Crowd-Funding tools allow for a wide-base search of financial resources by the collaborative funding through internet. This service is being offered by an increasing number of specialized companies, albeit still with limited financing range (Howe, 2006). These companies have raised over US$ 2.7 billion overall, and this was projected to grow to US$ 5.1 billion in 2013 (Barnett, 2013). Originally, the model was implemented as donation-based funding, through the collaborative attainment of a funding goal in return for rewards or products. Recent developments in crowd-funding initiatives include Investment Crowd-Funding where investors also become shareholders of the newly formed company, Localization Crowd-Funding where the funding search is focused on participants in specifics neighborhoods or cities, Group-Based Approaches, and Mobile Solutions (Barnett, 2013).

Macro-Working, also known as Macro-Tasking, is the outsourcing of modular activities that can be done independently, require a fixed and known amount of time, and which demand some sort of specialized

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[4] http://techshop.ws/
[5] http://fab.cba.mit.edu/
[6] https://artisansasylum.com/
[7] http://maker-works.com/wordpress/
[8] http://www.columbusideafoundry.com/
[9] https://noisebridge.net/
[10] http://www.hacdc.org/

knowledge. Examples of companies that offer Macro-Tasking market environment are Elance[11], oDesk[12] or the Virtual Student Foreign Service (VSFS)[13]. These services constitute outsourcing platforms for newly formed enterprises.

Micro-Working is the outsourcing of modularized activities (Howe, 2006), with the aim of completing remotely, activities which do not require specialized technical skills. These activities are traded in Micro-task markets, allowing the possibility of engaging a large number of individual persons for low individual times, and overall lower process costs. Studies have shown that although these model of crowdsourcing allows for a quick collection of user measurements, it is particularly important to define the tasks appropriately in order to obtain bounded results (Kittur, Chi, & Suh, 2008). A prominent example of this service, is the task-market offered by Amazon's Mechanical Turk[14].

Specialized Team-Sourcing, through spaces that promote positions and interested professionals around Hardware Startups. Sites such as AngelList[15] are leading this specialized trend.

Notwithstanding all of the above, Hardware Startups have historically not been able to attract wide participation of venture capital, accounting for less than 1% of total investment in startups from 1992 to 2011. Even taking into account recent surges in the number of hardware startups in the U.S. economy, in 2013 less than 3% of investments were directed towards these types of companies (Wakabayashi, 2014).

Concerted efforts are being pursued by governments and economic institutions to foster the generation of startups, and copious documentation has been produced as guides for startups. However, little has

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[11] https://www.elance.com/
[12] https://www.odesk.com/
[13] http://vsfs.sparked.com/
[14] https://www.mturk.com/mturk/welcome
[15] https://angel.co/hardware/jobs

been written about the Operations and Supply Chain requirements for Hardware Start-up Companies, and about strategies for the skills required to build flexibility during the initial phases of startup development.

As an example, an Amazon.com search for the term "Hardware Startup" delivered only 6 relevant book results, while the search for the term "Startup" delivered over 21,000 book results[16].

	Google Scholar	**Web of Science**	**Amazon.com**
Business Startup/Venture Guidelines	31,200	3,698	21,460
Hardware Business Startup/Venture Guidelines	547	57	6

Table 1 - Sample Search results for Hardware vs. Startup References[17]

Recent surveys of literature used in Top-tier universities in the U.S. show that there is a gap in the information that is being delivered to potential entrepreneurs on the particular characteristics of a Hardware Startup, and an emphasis on Financial and Marketing aspects over Operational and Supply Chain Skills (Buckley, 2013). In the particular case of Hardware Startups, some literature has described the relevance of an effective Supply Chain, in particular with the conditions in which the company is embedded (Fine, 1998).

[16] Search was carried out in April 2014
[17] This table shows a sample search for instances with and without the word "Hardware" within the context of Startup or New Venture Business references for the search engines indicated. Search performed on 13 March 2014.

3 The Robotics Industry

Initially the Industrial Clusters are characterized and the Massachusetts Robotics Cluster is then further described.

3.1 Industrial Clusters

Clusters are geographic concentrations of interconnected companies, specialized suppliers, service providers, and associated institutions in a particular field. Clusters come about from the value they add to the participating organizations, as they increase the productivity with which companies can compete through enhanced communication and response times (Porter, 1998).

Clusters promote both competition and cooperation, and the project development cycle times typically are much lower than in environments without clusters present. Clusters additionally influence competition in at least four explicit ways:

- by promoting the creation of businesses in the cluster area (either through the creation of new startups, or the creation of new endeavors from existing, established companies),
- by improving medium-term performance of startups through the improvement of the level of employment of young startups (below 5 years old) thus raising the survival mean time for new businesses,
- by driving and promoting the rate and direction of innovation for companies within the cluster, and
- by increasing the productivity and performance of companies present in the area (Delgado, Porter, & Stern, 2010; Porter, 1998).

Clusters can be described at least by three dimensions, namely Cluster Geographic Scope, i.e., the physical location and territorial extent of the companies having interdependent activities and ongoing relationship, the Cluster Breath, i.e., the scope of related industries that constitute ongoing interdependencies, and the Cluster Depth, i.e., the extent to which the supply chain (upstream and/or downstream) is integrated into the cluster activities (Enright, 2000).

The development and upgrading of clusters is an important item in the agenda of governments, companies, and related institutions, such as Universities and NGO's. Cluster development initiatives are an important new direction in economic policy, building on earlier efforts in macroeconomic stabilization, privatization, market opening, and reducing the costs of doing business.

3.2 Massachusetts Robotics Cluster

The Robotics Cluster present in Massachusetts has its origins in the 1960's with the foundation of the Artificial Intelligence (AI) research group at the Massachusetts Institute of Technology. Much of the research and technological development carried out during this period was through funding by the US Department of Defense (DoD), and its Advanced Research Projects Agency (ARPA). Some prominent research results from this period are the LISP programming language developed by John McCarthy and the Minsky Arm in 1967.

The first spinoffs from these Institutions were generated in the early 1990's, when companies were founded through teams led by MIT professors, such as iRobot in 1990 led by Rodney Brooks, Colin Angle and Helen Greiner from the MIT Artificial Intelligence Lab, and Boston Dynamics in 1992, led by Marc Reibert.

The Massachusetts Robotics Cluster is a complex interaction of companies and institutions around the research, development and manufacture of robots, in well-defined categories which include the robotics companies themselves as well as supporting organizations, such as academic and research institutions, suppliers, downstream vendors and governmental agencies (Khamis, Utembayev, Nordin, Victorero, & Abughannam, 2012). These categories are depicted in Figure 1.

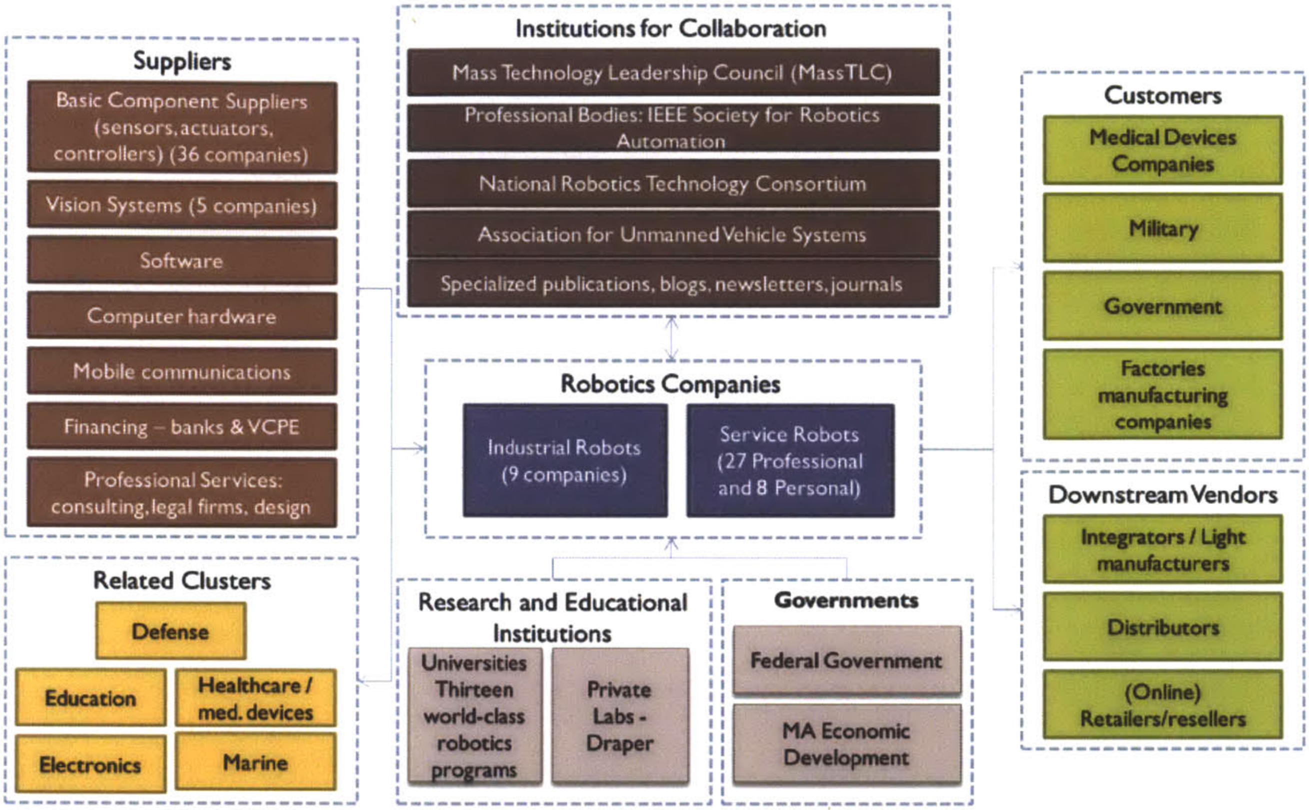

Figure 1 - Massachusetts Robotics Cluster Map [18]

The Massachusetts Robotics Cluster was formally established in 2005 by the Mass Technology Leadership Council (MASS-TLC) to *"bring together companies, institutions and individuals engaged in robotics research, education, product design and commercialization.."*[19]. The MASS-TLC reported in 2009 a booming Massachusetts Robotics Industry with over US$ 942 million in sales, employing over 2,500 professionals (90% of which were local hires), with an average growth rate of 47%, and with over 40% of the existing companies in the cluster with 6 years or less in the market. However, only 20% of the 75 companies surveyed, reported being funded by venture capital (Thomas Hopcroft, 2009).

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[18] (Khamis et al., 2012)
[19] (Tom Hopcroft, 2012)

While in 2013 the Massachusetts Robotics Cluster consisted of close to 100 companies, the broader cluster ecosystem is composed of over 200 companies, manufacturers, suppliers, design and engineering service firms, educational institutions, and research labs with involvement directly or indirectly in robotics[20].

Several competitive advantages were identified for the Cluster

- A critical mass of Universities with programs in Robotics or related areas
- An important number of companies based in the area that were innovative in a range of robotics applications
- Several Institutions doing world-class robotics research and development
- A base of highly skilled workforce
- A number of related and supporting industries

Their mission was defined therefore as threefold:

- Raise the awareness at a local and global level on the Robotics Industry in Massachusetts/New England
- Attracting resources as well as thought leaders to this Industry
- Promoting and accelerating the growth of new and existing companies by generating business opportunities

The interaction between companies in each of the categories do not necessarily pass through the Robotics Companies and there are several activities which occur around the companies actually generating the product to market, with activities related to the creation of skilled labor, technological exchange, and

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[20] The most recent data is available from the MassTLC 2012 survey for leading robotics companies in the New England area. It is worth noting that this survey had a 50% response rate.

knowledge research, for instance. The following figure depicts the different relationships present in the cluster and around the Robotic Companies themselves.

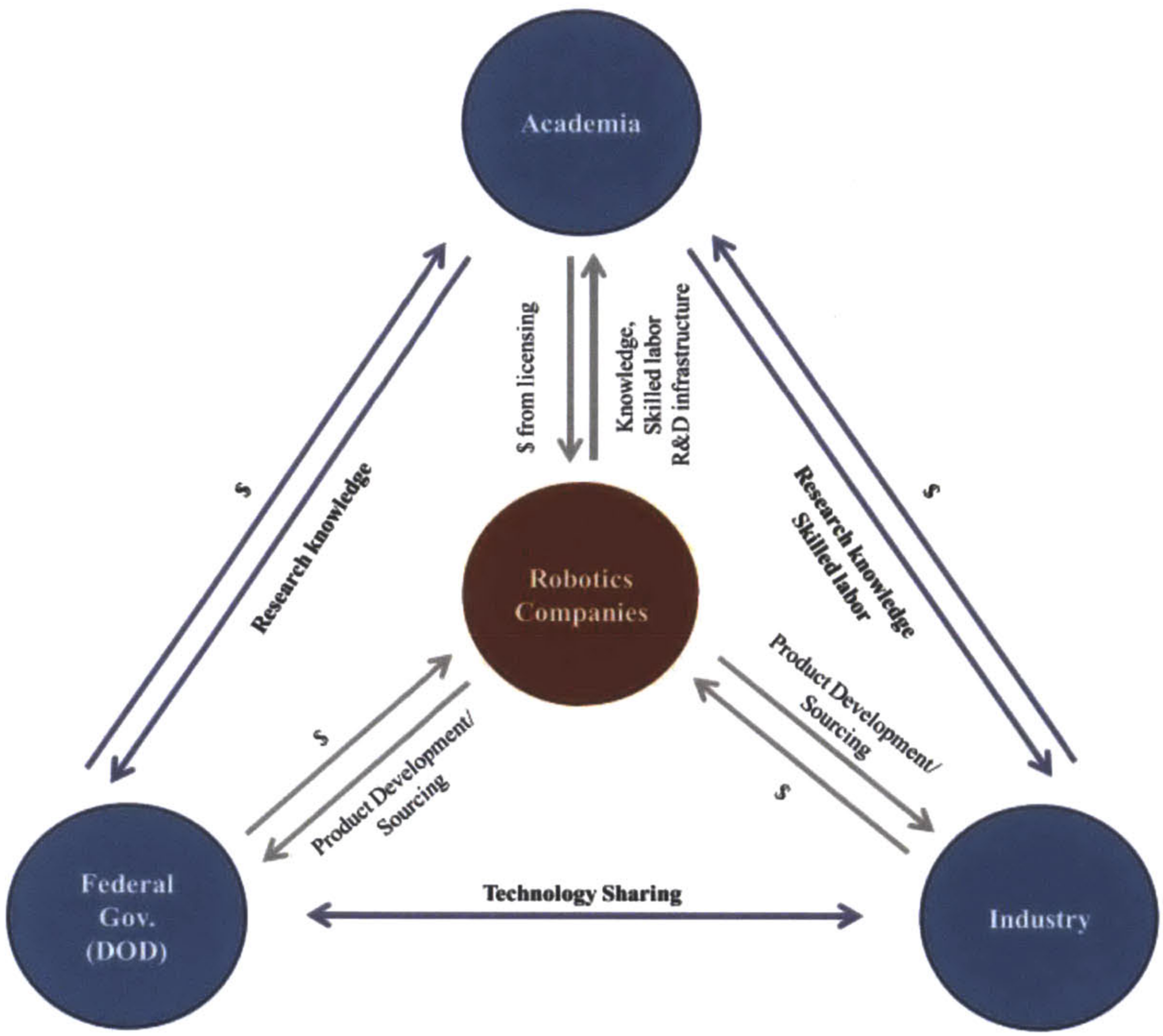

Figure 2 - Activities between the different actors in the Robotics Cluster[21]

Additionally, the Robotics cluster is linked to other relevant clusters present in the area through e.g., technological or human resources exchange and purchase of robotics products. These other clusters in

[21] Ibid 18

the Massachusetts Area include Defense, Healthcare/Medical Devices, Education, Marine, and Electronics.

There are several other robotics clusters present in the US, and the three most important in terms of number of companies and associate investment, are those located in Silicon Valley, Pittsburgh, and Boston. These clusters share some common features, albeit being located in different geographical contexts: they are all being nourished by Research and Development work being performed by leading universities in the area, and they have a strong dependence on government contracts for research and procurement (Khamis et al., 2012). The following table shows some of the characteristics for each of these clusters.

	Boston	**Pittsburgh**	**Silicon Valley**
Large Companies	*iRobot *Foster-Miller *Boston Dynamics	*RedZone Robotics *RE2	*SRI International *Adept Technology
Factor Conditions	*MIT and other universities supplying talent and research *High patent/capita (Boston 1st in the US)	*Carnagie Mellon University (CMU) as anchor school *High patent/capita (Pittsburgh Area is 23rd in US)	*Stanford and Berkeley producing top talents *Vibrant VC sectors *High patent/capita (San Francisco Bay area 2nd in US)
Demand Conditions	*Government procurement *Household, retail and medical consumers	*Government/Defense *Commercial and Medical applications	*Government/Defense *Industrial and personal robots
Related Supporting Industries	*Healthcare *Education *Specialized component firms *High Tech / low Volume Machining	*Medical *Software and design companies particularly vision learning	*Internet companies and start-ups
Context for firm strategy and rivalry	*Vibrant Startup and spin-off *National and international players *Proactive tax-incentives for R&D and Investment	*Many spin-off companies from CMU *Recent large grant from Govt ~ US$500M *Proactive Tax Incentives	*Entrant by big tech company like google *Proactive Tax Incetives *Strong Entrepreneural Mentorship

Table 2 - Comparative table of the three biggest Robotics Clusters in US [22]

[22] Based on (Khamis et al., 2012)

Although the Boston Cluster is considered to be the oldest one as well as the cluster with the largest number of robotics companies in it (until 2012 more than 80 companies, accounting for more than the Silicon Valley and Pittsburgh clusters combined), these have recently experienced big robotics-related investments by internet companies like e.g., Google, who purchased several robotics companies since the second semester 2013, including Japanese company Shaft Inc., several California-based robotics companies, as well as the Massachusetts-based company Boston Dynamics (Estes, 2014; Forrest, 2014).

4 Interview Methodology

The information that was required for this work was collected from selected companies according to a qualitative interview, this is, a conversation based on a pre-specified agenda covering the main points of interest for the research. These types of interviews are completed based on the answers of the respondent.

The methodology that was followed corresponds to a Qualitative Research Design technique known as the Interview Protocol. According to this methodology, an interviewee provides his/her particular viewpoints and experiences regarding a specific topic of interest. When the data gathered through these directed interviews is combined with other forms of data collection, the method can deliver a very robust body of evidence on which to perform analysis (Berg, 2001; Turner, 2010). Of the three existing Interview protocol formats available, the General Interview Guide approach was chosen, based on its flexibility for question wording, while having a definite structure on the contents that the interview is expected to cover (McNamara, 2011).

Interview Format	**Description**
Informal Conversational Interview	-Spontaneous generation of questions in a natural interaction -Interview Guided by interaction with Interviewee -Highly flexible, requires interviewer experience and originality in questions
General Interview Guide	-Questions cover specific areas of interest -Interaction Guides the depth into which each area is analyzed -Flexible in the interaction, more structured in the question scope, requires intermediate interviewer experience
Standardized Open-ended interview	-Questions are precisely worded and asked in the same order to the Interviewee -Highly Structured, required limited interviewer experience but will not react to unexpected information

Table 3 - Interview Protocol Formats (Turner, 2010)

The Interviews were implemented through the following main steps:

a) A preparation for the interview which considered a selection of the potential participants

b) Identification of the main areas that were required to be covered during the interview

c) The Construction of effective interview questions which would cover the chosen areas

d) Implementation of the Interview

e) Analysis and interpretation of data

4.1 Selection of Potential Interviewees

The process of selecting Interviewees considered two main criteria, in terms of what was required by the research:

Company Criteria: Following the objectives of the research, companies that would be considered for research interviews had to be related to the Massachusetts Robotics Cluster, be a startup with over 3 years of business experience, and ideally have a story to tell, in terms of particular strategic decisions which may condition its present success

Interviewee Criteria: Since the objective of the research was to obtain information regarding the skill evolution strategy within the company, while it was developing within its chosen business area, the interviewee had to be somebody who has passed with the company through these initial stages, be ideally part of the startup's strategic team, and had to be able to understand and put in perspective the decisions that were taken at each step in the company's development.

After looking for, three executives from relevant companies were chosen and interviewed as follows:

Name	Title	Company	Company Description	Interviewee Description
Ted Acworth	CEO	Artaic LLC	Artaic LLC, established in 2007, manufactures complex mosaics and murals with the help of robotics technology	Ted had the original business idea which he developed during his graduate study at MIT
Jim Daly	VP and CTO	Rethink Robotics	Rethink Robotics, established in 2008, manufactures Robots and automated applications for close interaction with Human operators	Jim participated early in the founding team and is the leader for the Supply and Operations strategy at the company
Mick Mountz	CEO	KIVA Systems	KIVA Systems, established in 2003, manufactures Robot Drives used in Warehouse Management.	Mick envisioned the original Product/Service Idea, and assembled the rest of the founding team

Table 4 - Interviewees Summary

4.2 Aspects to be covered in the interview

The areas to be covered in the interview were aimed at gathering the startup's journey experience in the following main categories: Supply Chain/Operations Strategy, Supply Chain/Operations Human Resources Development, Supply Chain Process development, and Supply Chain Relationship Formation and Management.

Of these Main aspects, a series of 10 main areas were identified in each of these Main Categories, and which composed the Interview contents:

Categories	Areas
Supply Chain/Operations Strategy	Supply Chain Development Strategy
	Supply Chain Relationship Philosophy
	Make-Buy Strategy and Decision Making
Supply Chain/Operations Human Resources Development	Internal Supply Chain Management capability development
Supply Chain Process development	Concurrent engineering of Product Process/Supply Chain
	Data Analytics/ tools applied to SCM
Supply Chain Relationship Formation and Management	Supplier Selection Criteria
	Supplier Performance Criteria
	Intergration of own with supplier's capabilities
	Lessons from successes and failures

Table 5 - Main Categories and Interview Areas

4.2.1 Make/buy strategy and decision making

The decision to either manufacture in house or to purchase the goods from a supplier, has several important implications on the types of capabilities that are required by a startup, both in terms of infrastructure (e.g. equipment, warehouses), and in terms of specialized personnel to manage these activities.

4.2.2 Supplier selection criteria

This aspect relates to the aspects the startup considers as relevant for constituting a business partnership, and may relate to e.g., technological capabilities, business culture, operational flexibility, operational response speed, control systems, and vision alignment. The order in which these aspects are considered vary according to supplier leverage.

4.2.3 Supply chain relationship philosophy

All relationships have an overarching rationale through which decisions are made, and which condition how situations are evaluated. The philosophy that governs the supply chain relationships will determine important aspects such as communication frequency and content, degree of joint process development with suppliers, conflict resolution and supply chain issue management.

4.2.4 Supply chain development strategy

The Supply Chain Development Strategy is the plan through which the end result, usually conceived as a vision, is aimed for by the company. This aspect includes the resources that are being deployed, the timing of their deployment, as well as the risk analysis of potential development scenarios. The strategic decisions normally leave options open, and in case of irreversible decisions also restrict alternatives, conditions which in many cases are asymmetric.

For example, a Strategic Supply Chain Development Decision would be to build-in the capability of manufacture, which would imply sunk costs and a skill set required by the implementation team which would differ greatly from the option of outsourcing manufacture. An argument can be made that in this case, the options would be asymmetric, since the option of outsourcing can be changed to in-house manufacturing without the same costs as taking the opposite decision.

4.2.5 Supplier performance criteria/metrics

This aspect was centered on identifying the performance expectations for the suppliers, as well as the processes, tools and timing with which the supplier's results were measured against what was expected.

4.2.6 Internal supply chain management capability development

The internal development of Supply Chain capabilities has to do with the way in which the company built up its Supply Chain know-how, team configuration, implementation timing, hierarchy structure and flexibility considerations.

4.2.7 Integration of your capabilities with your suppliers' capabilities

The integration of the Owner's capabilities with those of its suppliers is something that is seen to some extent in established companies. The interview aimed to gather information in case this strategy was followed by hardware Startups, the extent to which this was possible, and to find out its implementation.

4.2.8 Concurrent engineering of product, process, and supply chain

The development the product engineering, manufacturing process or supply chain concurrently with the suppliers, is a potential alternative for hardware-startups. Insights would include process configuration and control, and characteristics of the teams involved.

4.2.9 Data analytics/tool applied to supply chain management

Companies start using different tools at different points of their development. Important insights include the point at which the start-up decided or is projecting to migrate from spreadsheets to other more sophisticated control system, how these systems are connected among themselves and with any existing ERP system in the company, and potential systemic integrations with Customers or Suppliers.

4.2.10 Lessons from your successes and failures

An important part of the Interview was designed to be the open question about potential lessons the Interviewees have had from their start-up experience. Of special interest would be aspects relating to initial business considerations which proved to be otherwise in practice, or aspects which were not considered in the original conceptualization of the business along with the reasons why these aspects were not considered.

4.3 Interview Structure

Interviews were sought with executives in Robotics companies through direct request to its executives. The executives were contacted either through faculty-level contacts, or through introductions at Robotic Industry Seminars and Fairs in the Boston Area[23]. This request consisted in an email with a brief introduction to the research that was being done, along with the main aspects that were expected to be covered during the interview. Examples of these emails can be seen in the Appendix.

The email additionally indicated that a non-disclosure agreement could be signed if so required, giving explicit acknowledgement of the purposes of the requested conversation as well as the intended use of the information to be gathered. None of the interviewees required the signature of such an agreement.

The interview categories were covered in hour-long sessions, either on-campus or at these company's facilities. The conversation was recorded for easier transcription and subsequent in-detail analysis of the conversation. This was done previous request to the interviewees, and with explicit notification that the recording's sole use was to be for Thesis purposes. Every interviewees accepted this request for recording.

The general structure of the Interview was as follows:

[23] Two important instances to meet such executives are the MASSTLC Future of Robotics Summit held in Boston on December 13th, 2013, and the "Business of Robotics" Seminar at MIT during January 2014.

Interview Structure		% of time
	General Introduction (Professional Background & Interest in the area leading to the Interview)	5%
	Presentation of the research	5%
	Request for Recording of Interview	5%
	Leading, open questions on the areas of interview	60%
	Final Comments	10%
	Gathering of additional Data	10%
	Acknowledgement for Meeting and Closing	5%

Table 6 - Interview Structure

5 Case Studies

The main aspects of the interviews held with the robotics companies will be described next, considering the interview framework described in section 4.1, and with an emphasis on the role of their supply and operation skills development in their current achievements and future plans.

5.1 Arctaic

Arctaic LLC is a Boston-based company started in 2007 by Ted Acworth, an MIT Sloan Fellows alum, who developed his idea during his time at MIT. He saw a business opportunity in building a business that would specialize in the generation of highly complex mosaics for the Construction and Interior Decoration industry. This business is dominated by a very few manufacturers who are well known in the industry and which normally obtain the main contracts. These main suppliers normally source in China, specialize in high quantity, standard product delivery, but present operational difficulties when faced with mosaics that are unique, large and/or highly specialized.

Normally highly customized architectural features are required with little lead time and are very labor intensive. These customized mosaic arrangements are normally manufactured through a process of pixelation (see section 5.1.1), and subsequent mounting at the site. The traditional method of mounting these patterns is by hand, process which requires specialized labor, is time intensive and highly prone to errors.

The service provided by Artaic LLC., was initially defined as the delivery of custom-made mosaics, covering the stages of architectural design, pixelation and later manufacture of a product in a standard format ready to be assembled and mounted on-site by workers with no special training additional to the one required to install normal tile panes. The tile industry has very specific standards for the format in which the materials have to be delivered to the construction site (e.g, ASTM Volume 15.02 Glass; Ceramic White wares), so the value proposition consisted in a quick design-to-delivery lead time with minimal impact on the construction site efficiency.

The reduced delivery lead time as proposed by Artaic was driven by efficiencies during its operational processes, and based on two proprietary concepts: the pixelation process and the robotic mosaic tile pane assembly.

5.1.1 Production Process

The production process is divided mainly into the Pixelation and Pane Assembly phases.

Pixelation Phase

The Pixelation process is the transformation of an image to a series of small, single-colored display elements. These elements can be squared, but there is a growing percentage jobs that request other shapes, such as triangular or hexagonal. These elements are then arranged into standard size tiles which are then marked with a specific coordinate for correct on-site assembly. Each tile is therefore unique (coordinates will not occur twice in the same assembly), and when assembled correctly will generate a pattern that, when looked upon from a distance, will resemble the original customer image. A software developed by Acworth and some of its early contributors, allowed for a Pixelation that took into consideration factors such as the tile color tones, tile texture and tile sizes, as available from their approved suppliers. This allowed for expedited generation of purchase orders from Artaic's suppliers, material that was ordered on a per-project basis, allowing it to have only enough inventory for the generation of samples for potential customers.

From this pixelated image, the software thereafter generates a grid of standard-size tiles (each of which will contain many pixelated elements), gives each tile a coordinate, and codes the instructions for the robotic Mosaic Tile Pane Assembly process for each of the tiles.

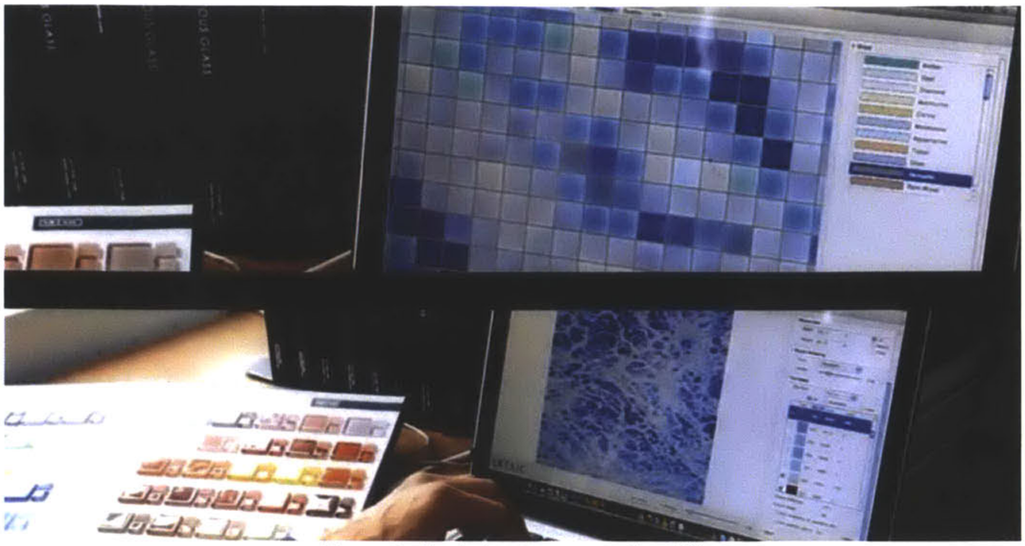

Figure 3 - Pixelation Process at Artaic[24]

Robotic Mosaic Tile Pane Assembly Phase

The Robotic mosaic tile pane assembly consists in the process of building up and marking the individual tiles from a series of pixelated elements.

This is accomplished through a standard pick-and-place robotic arm, and following the code created in the pixelation stage for the movement of the robotic arm. This Robotic Arm was fed by a supply of pixelated elements (tiles of size 1 to 2 inches in width) arranged in several sequential delivery panels actuated by gravity. The Robot Arm picks these elements and places them in a plastic grid which then serves as base for the application of the cement.

This process is in itself highly accurate and, according to Acworth, 10 times faster than a manual alternative. This method is, however, not easily scalable, and requires a substantial space for the safe placement of the robot.

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[24] Picture from "The Craft of Artaic – Innovative Mosaic", https://www.youtube.com/watch?v=1yBrd2-PE14 accessed on 23 March 2014

Artaic has been developing a faster solution for the mounting of the tile elements, through a system of electric actuators, which would deliver correctly mounted tiles at a speed 10 times faster than the robotic arm.

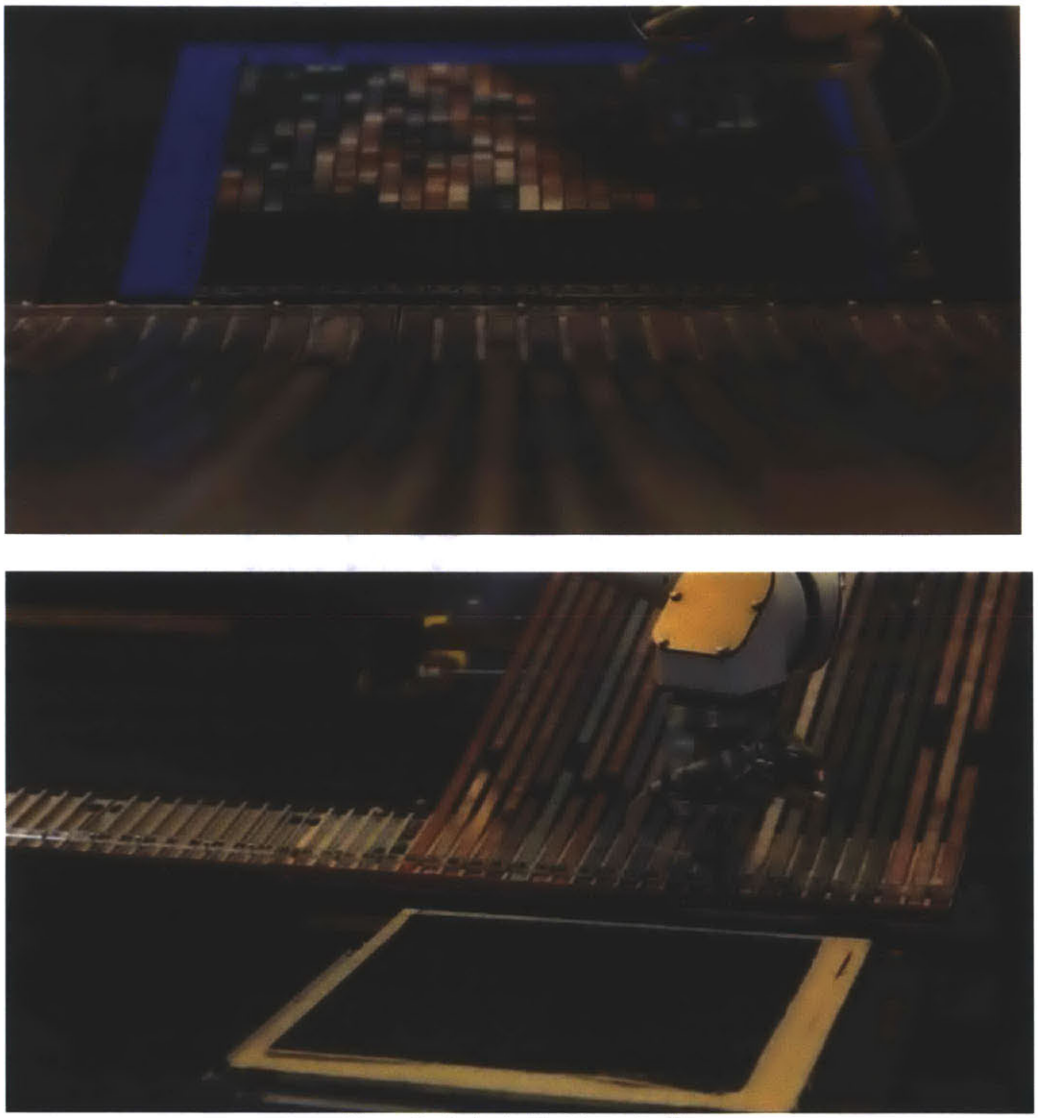

Figure 4 – Robotic Tile Mounting[25]

[25] Picture from "The Craft of Artaic – Innovative Mosaic", https://www.youtube.com/watch?v=1yBrd2-PE14 accessed on 23 March 2014

After the Robotic Tile Mounting Process is completed, an adhesive polymer is applied to the tile through a manual process, which will keep the arrangement in order for the next process steps at Artaic, through Delivery and until the tiles are mounted on-site.

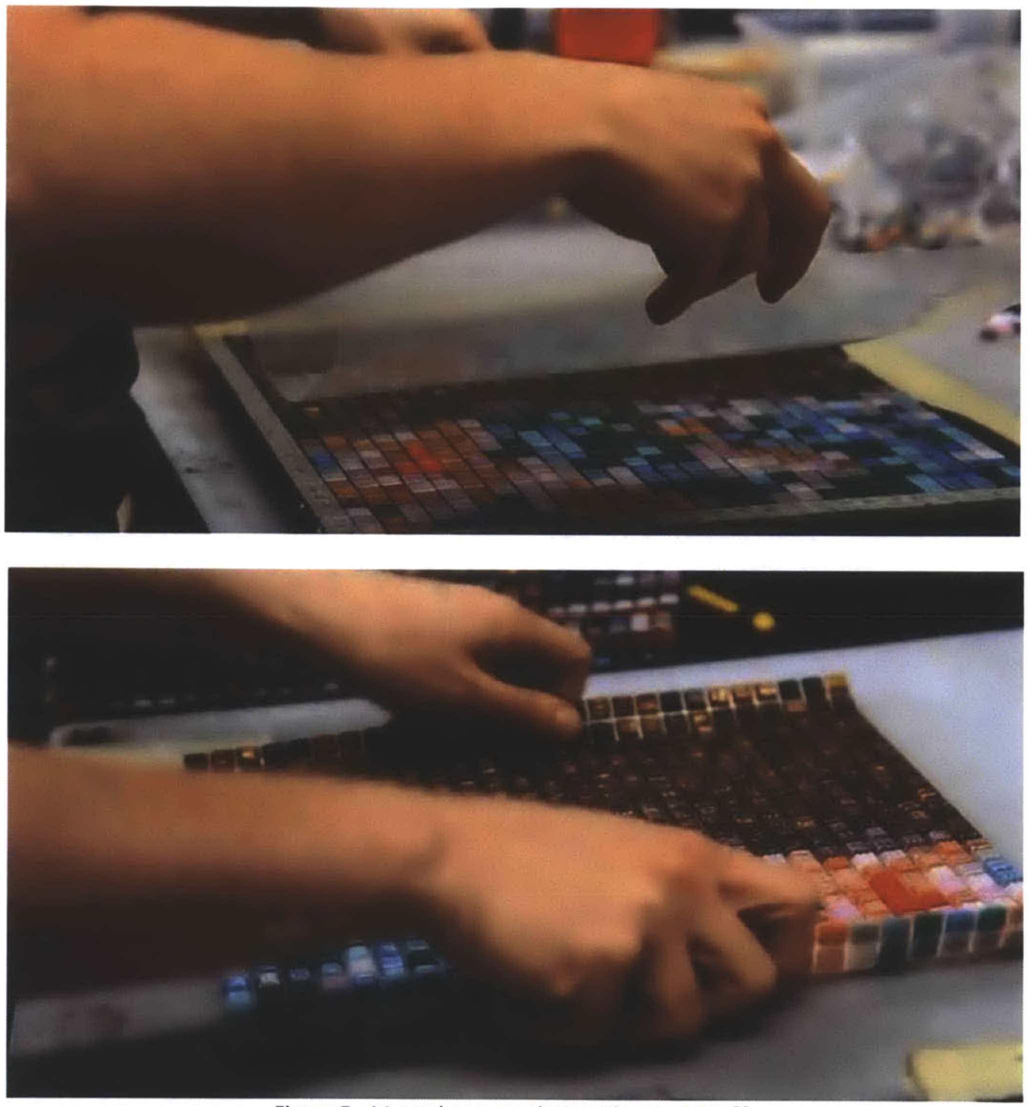

Figure 5 - Manual process during tile mounting[26]

Mosaic Revision and packing

[26] Ibid 7.

Once the different mosaic tiles components are mounted, the adhesive sheet has been applied and the tiles have been marked, the complete set is arranged for revision at the warehouse, a Tile Map guide is created, (Picture and diagram of the mounted mosaic, indicating the position for each of the tiles) and the tile set is subsequently packaged and sent to customer.

Figure 6 – Pre-shipment Mosaic revision and Packing[27]

[27] Picture from "The Craft of Artaic – Innovative Mosaic", https://www.youtube.com/watch?v=1yBrd2-PE14 accessed on 23 March 2014

5.1.2 Supplier development

Artaic decided upon a strategy of restricted inventory, with sufficient stock for the fabrication of product samples for potential customers. Artaic also decided to procure material for final projects only at the time of Project Award.

The strategy therefore considered including the current lead times in the project proposal, and in obtaining an agreement for final delivery terms with the customer and the Supplier at the time of project award. This strategy was aimed at maintaining the Inventory at a minimum (reducing warehousing requirements) and avoiding obsolete items, since most of the inventory could be used for the product samples.

Artaic faced two main problems at the time of looking for suppliers: its quantity requirements, and the format of the raw materials needed for the specific manufacturing configuration at Artaic.

In terms of the quantity, Artaic projected purchases which were orders of magnitude smaller than those by the major actors in the industry, condition which did not allow Artaic access to a very diverse range of suppliers at the start of its supplier. Potential suppliers were contacted mainly at Specialized Fairs and raw material manufacture was located mainly China and Italy.

The Italian suppliers supplied a higher quality material, but at a higher price. They were, however, more dependable than the Chinese suppliers, who in a couple of instances supplied Artaic with material for an initial purchase (normally directed towards mounting of samples for potential customers), but who declined to continue providing even after a deal had been closed with a customer, arguing that the quantities required were too low, and therefore unattractive to them.

With respect to the raw material format, Artaic required 1 to 2 inch wide elements, while the suppliers in the tile industry provide standard size tiles which range from 10 to 17 inches in width. These tiles are however, normally composed of smaller tile elements, so Artaic's request would demand these suppliers go upstream in their production process and make available their product before it was assembled into tiles. This has proven to be very difficult to accomplish, further limiting the range of potential suppliers of raw materials for Artaic. One of the potential sources of this difficulty, as indicated by Acworth, was the limited supplier relationship management that has been done with Chinese suppliers. The relationship contacts are mainly through meetings at Specialized Trade Fairs, and no factory visits had been arranged with this suppliers up to the end of 2013. When considering the "Ganxi" concept, very strongly present in south East Asia, which describes the expectation between trade partners to have a personal connection which complements the commercial agreements, this might be a factor to delay the potential implementation of Artaic's requirements.

5.1.3 Supply/Operations skills development

The approach Artaic took to the development of its supply chain was gradual, and especially intensive from the point in time when the Supply Chain was finally conceived as the company's third strategic pillar, together with Design and Manufacture.

Supply Chain was not originally viewed as strategic by Acworth and his original team. Although he had Basic Operations Management Studies acquired during his studies at the Sloan Fellows program at MIT, the crucial role Supply Chain was to play in materializing the value proposition to customers was only realized at the time it was necessary to request the quick and unexpected reaction of a supplier to comply with tight customer due dates after unforeseen logistic delays.

Artaic's Supply Chain and Operations knowledge was originally concentrated in its founder, and eventually was expanded to a small team of supply chain generalists. Artaic's initial team in 2006, required every member to manage some part of the supply chain, in a multi-tasking environment with, as yet, little specialization. At this stage, the external Supply Chain (i.e. contact with the suppliers) was managed by the founder, and the inbound logistics, inventory management and outbound logistics were being managed by other members of the team.

In 2012 a supply chain specialist was brought in, to manage the relationship with suppliers, and to obtain a greater flexibility in terms of supplier dependability and number of approved sources of raw material. This position has control over the all inbound logistics and Supplier Relationship Management. Exploration of new supplier markets, and eventual generation of contracts with alternate suppliers is still in the hands of the founder. The Supply specialist will, however, recommend and work closely in materializing these deals.

At the time of this study, Artaic has a team of 23 people in total, with 3 of them dedicated exclusively to Supply Chain Management. It is, however, still developing its team, as its operations are bound to increase due to its additional assembly lines through the use electronic actuators.

5.1.4 Lessons learnt

Artaic's experience so far in the development of a service/product based on a robotic technology, has been a successful one, as it has been able to capture a lower volume, high variability but also highly profitable market segment with specific requirements which it is serving better than its competitors.

This performance has delivered a series of lessons, realized by Acworth and mentioned during the Interview for this Report. The supply-chain-related lessons are summarized next:

- **Supply Chain is the Third strategic pillar in a Hardware Startup**, additional to Product Design and Manufacturing. This was evident once the SC flexibility was required to overcome unforeseen logistic delays and delivery date changes by the customer.
- **Supplier engagement** has to be sought from the beginning of the process. Although transactional purchasing is the immediate alternative when starting with a new product/service, an outlook on

the eventual differentiating characteristics of the supply or eventual scaling needs of the business will require a flexibility from the part of the suppliers. This flexibility, in particular when considering suppliers form other latitudes and cultures, will require the fostering of a longer-term relationship. Artaic realizes it will have to act on this for its Chinese suppliers, in order to fulfill customer requirements in a timely manner.

- Supplier Engagement has to be **explicit**, and allows for a greater degree of leverage when considering the low initial volumes required by a startup. Artaic has approached this through the presentation of Letters of Intent to potential suppliers, with varying results, as some of these have been signed while other suppliers have rejected them.
- Maintain a **close relationship with your logistic supplier**, as these can be crucial in complying with Customer requirements, and in maintaining relevant logistic information updated and visible
- **Codify the Supply knowledge** so it is less people dependent and can be transmitted in an easier form to other team members. Artaic is still very much dependent on the knowledge of its team members, situation which very likely to be unsustainable when considering the complexity of an enhanced and growing operation.

5.2 Rethink Robotics

Rethink Robotics is a hardware manufacturing company started in 2008 with a team led by Rodney Brooks, Computer Science PhD at Stanford in 1981, and at that point in time Faculty at MIT since 1984. Brooks had previously founded iRobot in 1990 based on his experience with the Computer Science and Artificial Intelligence Laboratory (CSAIL) at MIT. The initial co-founders were Rodney Brooks and Jeff Bezos (founder of Amazon), figures which in themselves gave Rethink Robotics an initial leverage and visibility uncommon for these types of startups.

At the time of creation of Rethink Robotics, iRobot was a very successful company with over US$ 100 in cash flow due to their very successful product "Roomba", a robotized vacuum cleaner designed and developed initially at CSAIL and later manufactured in China, which was available to the mass consumer market for around US$400. This product represented a big innovation in the market, since the closest, similar product that had been available until then was an automated Vacuum cleaner manufactured Electrolux, available in Europe only, trading at the price of 2000 Euros (NPR, 2014).

However, when iRobot's board of directors was presented by Brooks with the plan of a research project to develop a robot that would interact with humans, they decided against it. At this point, Brooks contacted potential investors, including Jeff Bezos who he had met at a TED conference in California, to propose the idea of starting a new company to house this research plan.

The process that was followed in developing Rethink Robotics' Supply Structure was in a great deal conditioned by Jim Daly's vision, as well as his ability to communicate this vision to the company board for approval, and his skill in subsequently implementing this plan. The process is in its structure and coherence highly unusual for Hardware Startups, and has certainly contributed in a (as yet undetermined but certainly non-trivial) measure to its success.

In 2012 Rethink Robotics launched its first consumer product, a robot named Baxter, designed for a direct interaction with human operators, and a base price of US$22,000 (Kirsner, 2012). Its potential applications include Material Handling, Line loading and Unloading, Testing and Sorting, Machine Tending, Packing and Unpacking, Light Assembly, and Finishing Operations.

Some of the unique characteristics of this robot are its ability to be trained intuitively by line operators directly, since it learns the sequence of its movements by first being led by the operator through the different steps. Additionally it has sensors which allow it to operate in close proximity with humans

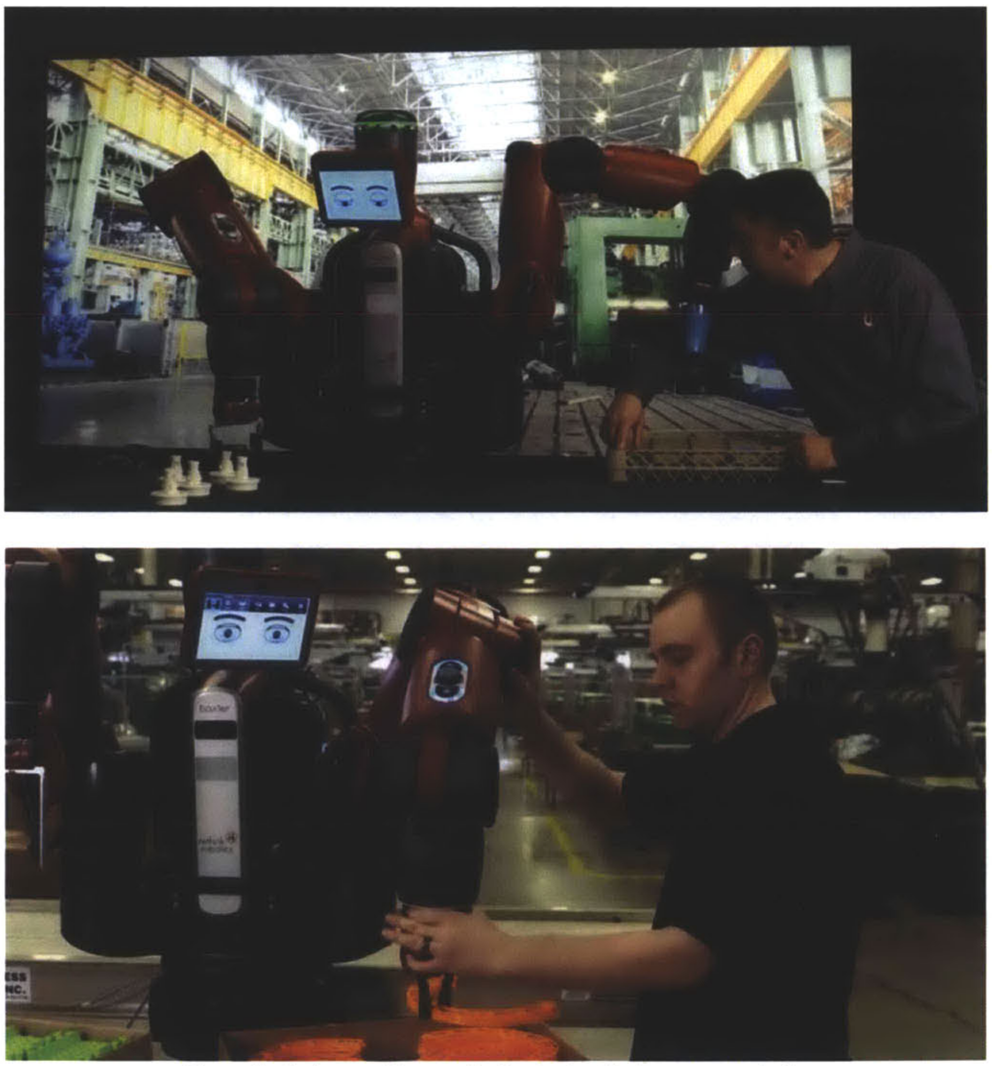

Figure 7 - Baxter working and being trained in human proximity

5.2.1 Supply Strategy

Rethink Robotics envisioned implementing a version of a Virtual Manufacturing Model, through which every design was to be modular and all manufacturing was to be outsourced. The vision of the Vice President of Product Development and Operations, Jim Daly, was to outsource as much of the production process as it was possible. Daly's previous experience as VP pf Operations in consumer startups Zeemote[28] (computer gaming applications) and Tea Forte[29], had led him to the belief that Rethink Robotics should concentrate its operational efforts as much as possible in the core capabilities of the business outsourcing the rest to a so-called "Virtual Operation" who would be involved even before the product designs were finalized. Through this vision, the Owner company would not fabricate anything themselves, and would just manage the process, offsetting some of the risks own to inventory management to its suppliers.

The main advantages that were expected from this configuration were:

- Lower required working capital, as the main capital investments were undertaken by the suppliers, who were expected to take part in the design process, manage the complete sourcing, manufacturing, WIP and Final Inventory management and Storage, packaging and delivery, as well as the quality control process.
- Rethink Robotics would be able to concentrate in its core competencies, which were identified as Product Design, Marketing and Relationship with Customers, High level Operations, and Reduced Prototype building and Testing.
- The Modularized components would allow for eventual supplier competition and thus company flexibility in case suppliers needed to be replaced.

[28] http://www.zeemote.com/
[29] http://www.teaforte.com/

- Higher availability of Cash Flow, since Suppliers were paid in 45 days, and Customers pay in 20 days allowing for 20 to 25 days of free cash flow.

Baxter is a mechanical assembly of actuators, sensors and structural components, which is constructed based on modules consisting of the robots mechanical subparts, such as the robotic arm, main robot body or hand actuators. These subassemblies were designed as modular, and after being manufactured in independent processes, are then mounted into the final product, tested and packaged for final customer delivery.

The initial supplier configuration was then expected to consist of a main Implementation Subcontractor who would be selected due to its skills in managing most of the process including product specification, raw material supplier search and selection, Production Processes, Quality Control, Packaging and Delivery to final customer. This Implementation Contractor would even take part in the prototype design and manufacturing processes. The initial Supplier Strategy was therefore divided into the Supplier Hunting Supplier Negotiation, and Supplier Management phases[30].

5.2.1.1 Supplier Hunting Phase

The Supplier Hunting Phase consisted in a screening of the market for potential suppliers suitable for the role of Implementation Subcontractor, followed by a very rigorous screening process of candidate suppliers. The leverage exerted by Rethink Robotics due to the high visibility of its two main investors, led it to have a potential supplier base which was more diverse that it would have had without this leverage. The main aspects that were considered during the Hunting Phase were Production Capacity, Production Flexibility, Production Capabilities, Production Quality and Cultural Requirements, explained in detail next.

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[30] Sepulveda, D. (23 October 2013). Personal Interview with Jim Daly.

Production Capacity: The first requirement for a potential supplier was that their available installed production base had to comply with the projected initial production requirement of Rethink Robotics, usually reflected as throughput capacity for installed machines and personnel. Although the main existing actors had a production base much bigger than what Rethink Robotics initially required, their available production capacity due to committed production to other customers did not always comply with the production levels that were to be expected by Rethink Robotics. Additionally, a range of supplier sizes was also considered during the Hunting Phase, and a potential strategy originally considered, was to associate with a small supplier as the Implementation Contractor, and to develop this Supplier as the business grew, while outsourcing some of the risks associated with the manufacturing of a new product.

Production Flexibility: Daly's experience also allowed him to identify the capability of scaling operations or reacting to demand fluctuations, as a key aspect to evaluate during the Hunting Phase. This flexibility was evaluated based on existing and proposed Sub-supplier agreements held by the potential suppliers.

Production Capability: The capability relates to the know-how and infrastructure own to the supplier to provide a product according to the technical characteristics as required by Rethink Robotics. This included types of machines, tooling required, knowledge profile of its personnel (both own to the potential supplier and also at their sub-supplier) and supply chain management. Personnel capability additionally played an important part in the joint product development process that would be sought by Rethink Robotics after the Main Implementation Subcontractor was chosen. The Main Implementation Subcontractor had to manage the supply chain to its own production (supplier selection, auditing, performance indicators, issue management), as Rethink Robotics did not get into most of the tier-two[31] supplier selection or audit.

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[31] Although from a Supplier Category Management perspective Tier-2 Supplier are those that have been categorized as non-essential by specific risk analysis matrix, the meaning here is from a Supply Chain perspective, where a Tier-2 supplier are those from which a company's suppliers source their raw materials, or the so called, "suppliers of our

Important exceptions were those suppliers that provided a specialized element (e.g., Powder Gears) instances where Rethink Robotics' sourcing team would get involved in potential supplier evaluation and selection, and would then and over the management of these suppliers to the Main Implementation Contractor.

Production Quality: This evaluation criteria was based on existing quality management policies and procedures, including auditing results to their own activity and that of their subcontractors, as well as previous supplier performance records. This condition received abundant information for evaluation from suppliers (especially if we consider Rethink Robotics' relatively small initial production requirements) largely based on the considerable founder-leverage that Rethink Robotics possessed at that point.

Cultural Requirements: Daly's previous professional experiences had led him to work towards a product development process at Rethink Robotics that would be deeply integrated with its suppliers. This relationship would go beyond a merely transactional exchange, and thus required the Hunting Phase to devote an important part of its efforts to identifying a supplier that might be interested in projecting a long term business relationship based on joint results, was willing to assume some risks for the common vision, had the capabilities of participating directly in the product development process, and was willing to engage in a long term relationship, given that some of the sourcing cycles took 6, 9 or even 12 months[32].

This aspect was measured through the professional profile of the supplier's team that would be interacting with Rethink Robotics, policies present in each potential Implementation Subcontractor, and the evaluation of attitudes by management within the potential supplier that would give an indication that they would be willing to innovate. Clear cases of potential suppliers who had a low fit with Rethink

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suppliers". This latter definition is the one generally accepted by the Supply Chain Council through their SCOR model (Li, Su, & Chen, 2011)

[32] Sepulveda, D. (23 October 2013). Personal Interview with Jim Daly.

Robotics in this aspect, were the cases of those suppliers who had an established market, and who were doing the same process for many years. High fit was found with suppliers who manifested interest in finding new ways of generating the product or who were willing to look for alternatives that would go beyond their current production schemes[33].

As an integrated example[34], Rethink Robotics had to identify and select a manufacturer of Powder Metal Gears. Since there are not many manufacturers of this type of product in the US, the supply team initially narrowed the search down to three companies, given the type of items they produced and the technologies they were able to manage. The next step was to hand them a drawing of a mechanical components that did not exist yet, and ask them on how they would propose that element be manufactured, and were asked to manufacture a sample. This proposal was then evaluated by Rethink Robotics' Technical Area on product conformance to specifications and production sequencing, from the supply side in terms of the projected response time and from the management area in terms of the supplier response and cultural aspects of the relationship, which would play a defining role in product development cycles and issue management instances.

5.2.1.2 The Supplier Negotiation Phase

Once the Main Implementation Subcontractor had been chosen, the Supplier Negotiation Phase consisted in making explicit expectations of the way in which Rethink Robotics was projecting its work with this supplier. For this effect, the process was carried out in the following main phases: Walk through the designs, Capability Gaps Plans, Cost Requirements and Upfront Negotiation.

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[33] Ibid 32
[34] Ibid 32

Walk through the designs: At this point, the supplier participated in non-hierarchical meetings with Rethink Robotics technical areas, in refining the design through specialized input relating to raw material types or manufacturing insights so as to obtain a compromise between streamlining the production process (main concern of the Main Implementation Subcontractor) and maintaining a novel product and proposal to the market, while maintaining the fundamental aspects of the product design (main concern of Rethink Robotics). Daly describes these meetings as rank-less and without wearing the hats of any specific company.

Capability Gap plans: The design review and subsequent changes that were either detected as necessary or suggested as convenient, led to change requirements in the capabilities available at the Supplier.

Cost Requirements: A cash-flow was mounted with the supplier to understand cost structure beyond what was proposed in the initial process and after all additional requirements were incorporated. This led to a total yearly projected operating cost for the Main Implementation Subcontractor.

Upfront Negotiation: During this phase, the Cost versus Benefit tradeoffs were analyzed and a final production volume was agreed for the next year. Daly's vision wanted to have this variable in the process as constant, so as to get the negotiation out of the way, allowing them to concentrate on developing the product and achieving the shortest possible design to market cycle, especially since the company was thinking on continuous upgrade of the product once in the market (Stone, 2012).

5.2.2 Supplier Management

Since the production figures for the year had been agreed upfront, the Rethink Robotics' Supplier Management activities consisted mainly in Performance Measurement and joint Prototype Development.

The Main Implementation Contractor has the contact with all its sub-suppliers, and is responsible for doing quality audits as well as supplier performance and issue management. Rethink Robotics did not implement a Performance Measurement System with its Main Implementation Subcontractor for the first year of operation as, according to Daly, this was an adjustment period, and the measurement

5.2.3 Supply / Operations Skills Development

The Supply and Operations team at Rethink Robotics was assembled according to the skills that were required at each of the supplier development Phases. These steps were identified by Daly as Initial Consultant Advise, Sourcing Team coming in, Adding the quality team, and finally including the Operations team.

Consultants: The first phase of the Team development was carried out by specialized supply chain consultants, and could be considered a short-term supply team. The activity of these consultants took about 6 months and the consultant team was completely phased out after about one year.

The scope of their activities consisted mainly in two activities: Identifying the requirements for supply and operation teams within the company, laying out as a result an initial team development plan, and performing an initial market scanning for potential supplier to all the parts already identified by the engineering team.

The team requirements activity required a close contact with the product development team to consider their experience in the identification of potential supplier choices, as well as a supply perspective to consider those suppliers for which a sensible supply chain could be built, in terms of expected product development cycle times and supply lead times.

The supplier market scanning activity required a close interaction with the management staff at Rethink Robotics, to allow for considerations of budget, cultural restrictions or requirements in terms of the characteristics of this team, and required timeframes according to the overall company strategic plan. The consultant team also oversaw the initial hiring process, and phased out their activity at Rethink Robotics according to the arrival of the long-term Supply team's integration to the company.

The phase separation between short-term and long-term supply teams while in the initial formation of a company allows for a degree of risk control, since that during the short-term team phase, the company creates the option of quickly dissolving the team in case of business plan changes that would benefit from such a change.

Sourcing Team: Once the long-term supply team was assembled and an initial market scan was carried out, the next step was to start a supplier selection process. This required a strong role by the supply team as a liaison between the technical teams in the company (mainly design and manufacturing), as well as between these teams and the potential suppliers being evaluated.

The team member characteristics evaluated for this sourcing team were technical (e.g., knowledge of the sourcing processes, knowledge of the markets, negotiation skills) as well as cultural (e.g., a team player, open communication, psychological fit with the existing team, tolerance to the uncertainty own to startups).

Some of the activities that were included in this stage were the development of specialized tools for manufacturing, the development of sourcing and quality management processes, as well as the development of testing codes for the items that were being sourced. Another relevant activity during this phase was the generation of suitable contractual frameworks for these supplier relationships. This activity is highly technical and was accomplished through the advice of a law firm.

The final activity that was managed by this team, and once the suppliers were chosen, was the generation of prototypes. This included managing the cycle times by providing adequate and timely information to each of the areas involved (design, manufacturing), , company-supplier communication and issue management.

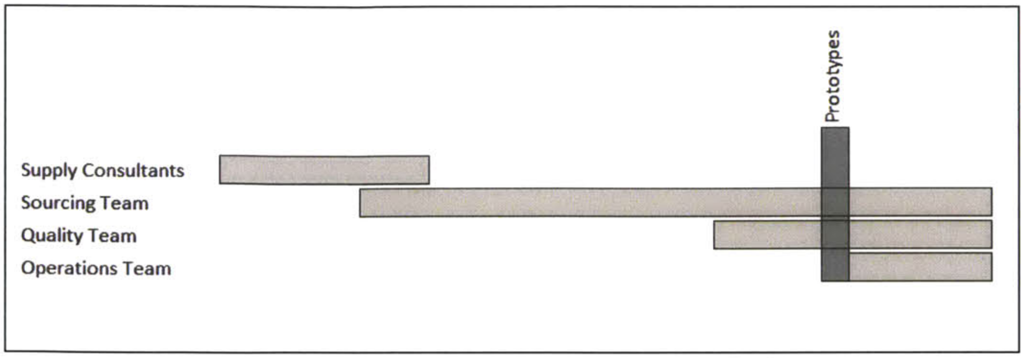

Figure 8 - Supply & Operations Team Formation overall scheme

Quality Team: Once the Prototypes were being developed, the quality team was brought in to oversee that the testing codes were properly implemented and to oversee the quality notification processes required for an iterative product development process. Their orientation was mainly oriented towards process quality management, and manufacturing quality at the suppliers.

The main characteristics sought for these team members were previous experience with testing codes, negotiation and communication skills as well as some cultural traits concerning team participation and leadership as well as issue resolution skills.

Operations Team: The last long-term team to be brought into the company was the Operations Team. Since no manufacturing was carried out in-house, these team members were selected due to their extensive relevant experience and technical expertise in industries relevant to the product modules they were assigned to (i.e., Electrical, Mechanical), their roll-up-sleeves disposition to face a problem on-site and to effectively solve these problems, and due to their personal ability to manage an external set of partners.

Supply Management Analytical tools

The Supply Management Analytical tools considered for the initial stages of this of this startup company was the use of the Microsoft Office Suite for Spreadsheet and Database Management and some analytical tools were developed in-house for inventory and prototype development cycle management. There was an explicit strategy of not investing in an ERP system, and since the evaluation of the Suppliers would start taking place only 1 year after the start of the contract, there existed no immediate needs to have a Supplier Relationship Management System.

Additionally, the Main implementation Supplier had within its functions to monitor and control the quality of its sub-suppliers, and this assigned company had therefore its quality management systems.

5.2.4 Lessons learnt

Some of the main learnings that Daly shared during the interview, were:

- Importance of having a **competent, flexible team** with a high attention to detail, allowing for quick effective changes throughout the company startup process
- Taking great care of the **Supplier Relationship Development** process, in terms of
    - Quality of Communication: An **upfront and straightforward communication** style
    - Issues can be declared in any **stream direction** expecting a direct and immediate involvement of managers prioritizing issue solution instead of guilt seeking
    - **Develop joint activities at different organizational levels** of the supplier and owner, which in Case of Rethink Robotics led to successful sessions where the line operators that were involved in the manufacturing of the product were taught on how to generate and execute a simple program on the final product. This allowed the participants to better understand the context in which they were performing their activity.
- A great product is crucial for the success of a company but it is far from being the determinant aspect in the development of a hardware Startup. **Supplier buy in and involvement** are crucial to achieve a process that will allow the vicissitudes of starting a company, since one of the few things that cannot be copied easily by competitors is the type and quality of the relationship a company has with its different partners

5.2.5 Company Challenges in Supply

The Challenges Rethink Robotics of facing at the moment come in the form of a market and competitors that are also being inventive in the way they manage their supply chain. This allow for a very short lived advantage in many of the innovations around the sourcing process.

Rethink Robotics has played around with a sourcing configuration which has allowed a control of the process without having a high economic burden in terms of investment in process-related infrastructure. However, this has not come cheap and the board of directors' intent is on cashing in on the investment that was effectively done in terms of nurturing the relationship with suppliers, to allow for a next phase of efficient supply chain with competitive prices.

5.3 KIVA Systems

KIVA Systems is a Company established in 2003, resulting from the groundbreaking vision of Mick Mountz, MIT Engineering Graduate and Stanford Engineering Undergraduate, of how warehouses should be organized and managed, influencing directly the Order Picking and Warehouse Arrangement processes.

The Order Picking process is a relevant Logistic warehouse process, through which the items required by a Customer Request are collected in their required quantities from the product storage locations (also known as buffer areas), and delivered to the Order Packaging Phase for eventual delivery to Customers. Warehouse Arrangement on the other hand, is the process of laying out the Items in a Warehouse according to pre-specified criterion.

The prevailing paradigm in most warehouses today is that the storage of goods is static, and the picking process requires an operator to access the storage location, find the item as required, and transport this item to the packing station. This can become very time consuming and labor intensive in the case of increasing number of SKUs (Stock Keeping Units), and in the case of products with difficult manipulation, especially those that have limited modular storage capacity due to e.g. irregular forms or fragility. Order Picking has been singled out as the activity requiring most labor and resources. These requirements, according to estimations, can reach as much as 55% of the total Warehouse Operations Expense.(de Koster, Le-Duc, & Roodbergen, 2007).

KIVA Systems' breakthrough proposal consists in allowing the storage racks to be transported to the picking point via an automated team of mobile robots (called Drive Units). These robots have a low profile and are therefore able to sequentially move in below a specific shelf module, lift this shelf module up, move it to a point in the warehouse where a human operator will receive the shelf module and perform the picking on the required item in that shelf, and then move the shelf back to a designated location in the warehouse.

This concept allows for the optimization of various aspects in Warehouse Design, including the order execution accuracy, the reduction of overall order throughput, increase use of labor and space, and increased accessibility to all items. The KIVA system concept of autonomous drive-units has also some advantages with respect to other warehouse automation approaches (e.g., sorters, carousels), such as a fraction of the implementation costs of a traditional automation approaches, since Kiva's average implementation costs US$ 5 million (Scanlon, 2009), faster design cycles, and increased flexibility through mobility and potential for expansion.(Wurman & Andrea, 2008)

The concept of Cellular Transport Systems is being developed by several other companies, such as the KARIS project at the Karlsruhe Institute of Technology in Germany, the ARMARDA project (Autonomous Reliable Material Handling Systems of Aggregated Redundant Distributed Actuators) or the ADAM AGV.(Kamagaew, Stenzel, & Nettstr, 2011)

KIVA was acquired in May 2012 by Amazon for a reported US$775 million in cash (Kucera, 2012). KIVA has since stopped looking for new customers and has mainly concentrated in developing its existing Robotic Designs (D'Andrea, Wurman, Barbehenn, Hoffman, & Mountz, 2011a, 2011b, 2011c; Wurman, D'Andrea, Barbehenn, Hoffman, & Mountz, 2011) for Amazon, and working on a Warehousing Management System that will evolve and adapt the Warehouse Arrangement dynamically according to the data gathered from previous required Pickings, resulting in increasing Picking Time efficiencies.[35]

Up to 2013, Kiva Systems had developed 2 models of robots, about 2 feet wide by 2.5 feet long, with a carrying capacity of 1000 pounds, a maximum speed of 1.3 meters per second, and a total recharging time required of 5 minutes per hour of operation. A typical implementation of these types of robots within a

[35] Sepulveda, D. (04 February 2014). Personal Interview with Michael Mountz.

warehouse consists of no less than 20 robots (with implementations in large warehouses counting over 500 of these autonomous vehicles), and prominent customers include Staples, Hershey's, and Amazon.

Figure 9 - Robot Drives transporting a Shelf module

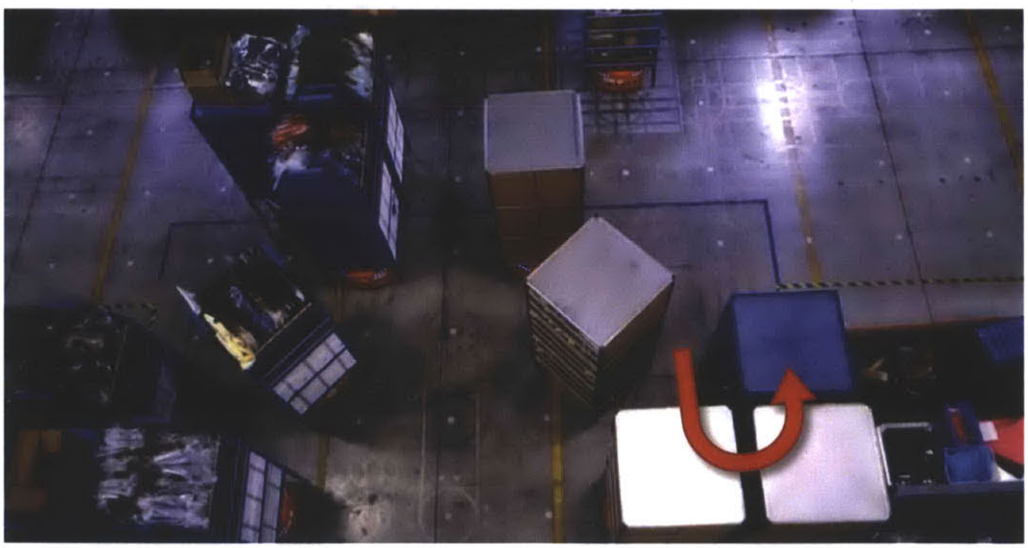

Figure 10 - Robot Drives lining up for Human Picking process indicating flow direction

5.3.1 Product Development Approach

From early on, Mountz implemented a structured product development process, known as the Product Roadmap, which consisted in a series of prototypes that were developed in overlap considering a specific timeframe and the different objectives that the company was aiming for at the different stages of its evolution.

Prototype 1 (2003-2004): This first prototype of the product was developed as a Proof of Concept. It was therefore manufactured with standard off-the-shelf components and there was no development of the Supply Chain involved other than the identification of suitable suppliers for the required standard components. All Designs were adjusted to the existing component sizes, and especially in the case of the batteries, this led to a clumsy but functioning first arrangement.

Although Mountz had the vision of the product that was to be sought, largely a result of his previous work experience in Webvan and Apple, he eventually brought in Pete Wurman (BS Mechanical Engineering, MIT and PhD Univ. Michigan) and Raff D'Andrea (BS Univ.Toronto, PhD. Caltech) in 2004 as technical co-founders, to refine the concept and lead in the solution of the technical problems encountered when the first product drafts were produced.

The main focus at this stage of product development was the time to market and the vendors were initially identified by the Engineering team that was doing the prototypes. One of the results from this stage was to identify potential pilot testing sites where to deploy a small set of Robot Drives.

Prototype 2, E Series (2005): This prototype was developed to be implemented in two pilot test settings, namely a section of one warehouse at Staples Inc., and another test site at a section in a warehouse in Hershey Co. Each of these deployments considered about 20 robots which had improvements in the design and a team that would oversee the implementation and be located close to the implementation Warehouse for immediate reaction in case of unforeseen events.

The Bill of Materials (BOM) for the construction of this initial group of Robotic Drives, was costly, since it had to be sourced from existing components available in the market.

Prototype 3: F Series (2006): The objective of the E-Series Prototype was to be swiftly implemented at each of the testing sites, obtaining a high performance (Low Cycle Times and High System Availability), while the learnings from this practical implementation were being applied into a next generation of robots

(The F Series), which were being developed in parallel and with the outlook of developing the product that would be eventually produced in a greater scale once the technical details that were picked up from the pilot test runs were solved and integrated into the product.

5.3.2 Supplier Development

The supplier development at KIVA followed closely the product development and depended also highly in the type of component that was being sourced. Although KIVA Systems form early on realized that their core competency was not in manufacturing motor drives, the management decided to assemble the product in-house. The main reasons mentioned by Mountz for this were:

- Since the Robot drives being developed by KIVA Systems was a new type of product with no other similar alternative on the market, Mountz decided that the start-up team was to generate this concept from the ground up, process which would be all the more complex if external outsourced manufacturing was considered.
- The In-house manufacturing that was considered was the final assembly of the Robot Drives. The different Subcomponents were sourced from specialized suppliers.
- The labor that was required for the assembly of the final robots was simple to acquire, and it was not highly technical.
- Given the quantity of Robot Drives that were projected for manufacture, resulted in In-house manufacturing being cheaper than outsourcing the Robot Assembly process.
- The team expected the product development process to be a iterative one and with at least quarterly revisions of the models. The management considered that outsourcing manufacturing would all a complexity to the process which would me this iterative product development process more difficult.

Another Strategic decision that was made early on by KIVA Systems, was to move the site of product development from California to Massachusetts. This decision was based on the perception by Mountz of the existence of a better manufacturing base, especially of Circuit Board Manufacturers, Machine Shops, and gearbox manufacturers, providing therefore a better hardware-oriented Supply Chain Capability.

Mountz also mentioned the particular example of the availability of low volume-high precision machining shops. The existing companies in the Massachusetts Area were servicing big defense industry contracts, and as these markets changed, these machine shops were left with surplus capacity which allowed their consideration of KIVA Systems' requirements.[36]

Only some of the suppliers participated in the design process for the components, and this involvement depended heavily on the type of component that was being sourced. About 70% to 80% of the component design was generated by the KIVA's Engineering Team, and this fraction was greater for components that were of the shelf, such as motor drives, while component specifications were more broad in the case of components that were more customized to KIVA Systems' needs and where the supplier had a manufacturing processes particular for KIVA's requirements (e.g., Metals, Castings, Circuit Boards and Machining Processes). In the Latter case, Suppliers often came forward with proposals for making the manufacturing process more efficient, and in some cases delivered suggestions on how to modify designs for a more efficient and cheaper manufacture[37].

Supplier's measurement also evolved through KIVA Systems' development. During the development of Prototype 1, the main emphasis was set on component delivery and availability. When number of Robot Drives being manufactured increased during Prototype 2, a greater care was put on the suppliers complying with delivery times according to the planned manufacturing sessions of these robots. Finally,

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[36] Sepulveda, D. (04 February 2014). Personal Interview with Michael Mountz.
[37] Ibid. 36

as the manufacturing of Prototype 3 was started, component cost and quality was looked into more closely.

During the first development phases of the company, defects were identified from problems in the functioning of the assembled Robot Drive. This was a longer process, as the faulty component had to be first identified and then the supplier contacted in search for a solution. As the Robot Drive manufacturing batch sizes increased, quality inspection of components was requested to the suppliers, before these components were shipped to KIVA. This allowed for a streamlined assembly and decreased rates of component failure at the time of Final Product Testing.

Testing Protocols were developed jointly between KIVA and its suppliers, and the quality inspection focus was set in identifying the minimum relevant set of key attributes for each of the components that needed to be measured, in order to obtain quality right off the Robot Drive Production Line.

KIVA only included the use of some Data Analytics tools after it had reached the Mature Growth Phase of the Company. However, Mountz acknowledges no Statistical Process Control has as yet been used in their production process. Additionally, KIVA has not implemented Information Exchange processes with Suppliers, for e.g., Quality Control.

5.3.3 Supply Skills Development

During the first phase of the product roadmap (Prototype 1), the suppliers for the Product components were chosen by the Engineering team, based on the standard components available in the market, and therefore no specialized Supply team was brought in by KIVA Systems.

However, during the E-Series Development (Prototype 2), a Vice-President of Manufacturing was hired, and who was chosen according to the following characteristics:

- Experience in hardware manufacturing companies

- Knowledge of roles required in the complete material sourcing process
- Ability and previous experience of working in a Start-up culture company
- Ability to work at a scaled up operation
- Ability to define the required roles for the projected Supply Chain and Operation requirements over time
- Ability to define and implement a deployment plan, i.e., coordinate the timely search and recruitment of suitable individuals to fill in these Supply Chain and Operations roles

The Supply chain and procurement roles profiles according to the product development phase were:

- For the Product pilot tests phase, the profile of the required supply team was that of generalists, i.e., professionals who would be able to perform as buyers as well as be able to negotiate vendor contracts. These roles even had to take part in production planning
- For the Mass Production Phase, the skill sets of the Supply Team members got narrower, requiring a more specialized profile to work either in the inbound, outbound or inventory Management processes.

5.3.4 Lessons Learnt

KIVA Systems is a valuable case of an individual with a vision, building a product and team from a mere concept to a multi-million dollar company, in an industry were breakthrough concepts had not been proposed for a long time. The main Learnings for Hardware Start-ups Mountz was able to share with us[38] are:

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[38] Sepulveda, D. (04 February 2014). Personal Interview with Michael Mountz.

- It is fundamental to **understand the core value of the company** you are trying to build, as this is the founding stone for every decision the start-up will make. This will for instance determine if the company will manufacture its own products, or if it will allow some other outsourced manufacturer to make the items for them. Additionally, the skills required for each of these decisions are vastly different.
- The Start-up has to decide upon, and **understand thoroughly the roadmap of the product** that it will develop. The Product Roadmap is the sequence in which the different versions of the product will be produced, timeframe, and the basic objective for each of these product versions.
- The Start-up has to **understand the objectives of the company throughout its evolution** to put in perspective was is expected of the team. An example from KIVA Systems' experience is the Battery Packs used by the different Prototypes of the Robot Drives. During the Second stage of product development, i.e, Prototype 2, and at the time of implementing the Pilot test with Staples Inc., and Hershey Co., the engineering team was not able to implement in time the Automatic Charging feature for the Robot Drives. Since the objective of the Phase was to do a Pilot implementation based on the proof of concept, a decision was made to leave the Batteries as replaceable, allowing thus for a faster implementation to market. The next prototype, included a bolted-down, internal battery pack, as well as the capability for the robot to charge itself.
- Build the products initially by hand and **add manufacturing capabilities to your Factory over time**, and according to the success of the product in the market. If the product is successful, the resources for automation will eventually be available. Don't get the investments out of sequence with the business growth.
- **Supply Chain configuration should be the result of the different market forces** that influence the Hardware Start-up. Therefore these forces should be identified and understood, e.g., Time to

Market, Cost, Quantity of Production, Quality of production, compliance with particular supply chain requirements due to stakeholder and/or contract restrictions.

5.3.5 Future Supply Chain Challenges

KIVA Systems' Supply Chain future developments take into account the existence of and established supplier base, who take part in a continuous process of product refinement. The Supply Chain evolution aspects that are currently being explored correspond to those of a company in its growth stage and have to do with

- **Dual Sourcing: Suppliers**: who can challenge the established supplier base have to be sought and encouraged to participate to a limited extent in the sourcing requirements of the company, in order to generate internal competition which has normally beneficial effects on quality and prices.
- **Contingency Planning**: Considering the future planned growth for the company, a way to leverage the risks derived from unreliable supply chain have to be studied. These plans may be derived from modularized sourcing and the generation of Issue Management Programs.

6 Summary of Interview findings

Based on the case descriptions in the previous sections, the following table summarizes the findings derived from the interviews with these 3 companies:

	Rethink Robotics	Artaic	KIVA
Make-Buy Strategy and Decision Making	A strategic decision was made early in the process to outsource as much of the sourcing and manufacturing process as possible, keeping the engineering and prototype development partially inhouse.	Given the propietary nature of the pixeling software and the robotic manufacturing of the mosaic tiles, an inhouse manufacturing strategy was chosen.	A strategic decision was made early in the process to do product development and Final prodcut assembly inhouse. Initial Prototype and E Series were manufactured with off-the-shelf components. F-Series required specialized components.
Supplier Selection Criteria	Suppliers chosen based on technical capabilities and high levels of quality required from the start. Additionally, cultural aspects were required (innovation culture) . Agility and flexibility were evaluated on a case-by-case basis, and depending on the product type.	Suppliers chosen based on: Quality (positioning of the company was in high quality products), availability to sell in required format (loose micro tiles), and willing to sell in the small quantities required by Artaic, much smaller than their big customers, who do not customize mosaics. Other product components follow industry standards, and there is therefore no customization necessary.	Initial Suppliers chosen based on technical specifications and price (designs used only off-the-shelf components), with no particular focus on quality. After 2 cycles of prototype development, Specialized Suppliers were required for customized components (e.g., Batteries, Electronic Circuits, Wheels). Additionally higher levels of quality and consistency were required from the suppliers. The third step has been to reduce costs, maintaining the quality already achieved.
SC relationship philosophy	Relationship approached as non-transactional, with expected and projected supplier development over time. Designs were walked through with suppliers from the start.	Supplier relationships have been varied, and Arctaic considers these relationships have been constrained by the limited product quantities required. There are several cases of chinese suppliers who have commited to selling product quantities for samples, and then has refused to continue providing product after a final job has been agreed by Artaic. Supplier relationship through meetings at Specialized trade fairs only.	No product development with suppliers. Some manufacturing and cost reducing alternatives have been proposed by suppliers (USA based, chassis manufacturers). Only after 4th stage of product path have suppliers been integrated to component development.
SC development Strategy	Development of Supply Chain is intended to happen though the 1st tier suppliers, who integrate the components, manufacture the final product and package the	Suppliers are contacted at Specialized Fairs in Italy, USA and China. Artaic requires the supply of individual tiles, which means suppliers have to go back in their supply chain, and not all suppliers have been able to provide this. There is therefore room for negotiation.	Initially off-the-shelf suppliers and open commercial channels. Second and third generation prototypes, when considering custome changes to standard compornents, led KIVA to work on operational changes within suppliers, opprtunity these suppliers used to propose more efficiente manufactuing methods and better materials.

	Rethink Robotics	Artaic	KIVA
Supplier performance criteria	On time product delivery, High quality requirements	On time product delivery	Intially: On time product delivery, functionality. Subsequent stages require High quality and component consistency. Latest phase focus on cost optimizations.
Internal SC management capability development	Founding team with consultant team generates supply plan and capability development schedule. Initially Supply Team and then Operations team integrated into the team.	Initial supplier search and contact managed by CEO. Generalist team in charge of inbound, outbound and Inventory Management Processes	Highly dependent on the VP of Manufacturing, who is in charge of planning and implementing supply team. Initial Team is mainly generalists and role specifications become narrower as activity increases.
Intergration of own with supplier's capabilities	No physiscal integration. Strong design integration. Customer service out of scope for suppliers.	No physical or product development integration.	No physical or product development integration.
Concurrent engineering of product/process/supply Chain	Intense concurrent engineering with first tier suppliers. Designs and prototypes are generated jointly.	No concurrent engineering with suppliers.	No concurrent engineering with suppliers.
Data Analytics/ tools applied to SCM	Intended to measure a steady state process. Scoreboard applied after 1 year of supplier engagement, to filter out variations due to developing relationship.	After 5 years of existence, no specific supplier KPI have been applied. Knowledge of supplier /operations performance is embedded in management and key personnel. Initial Toolswere spreadsheets and isolated software for accounting, Raw material data sheet at pictures, and Personnel Management. Limited integration of systems, and Artaic will participate in LGO program to develop integrated systems through a student team in 2014.	During the first 8 years of exietence, KIVA did not have an integrated SC/Operations Management system. Supplier performance mainly with management team and key personnel. Acquisition by Amazon will
Lessons from successes and failures	Founder Team and initial key personnel have to maintain a pragmatic apporach to product development, and be willing to go into the required technical depths to obtain a adecquate product. Supply Chains can be nurtured in a riibust manner by having a frank, direct communication from the outset of the company, at management and operational levels, consdiering joint activities with suppliers (specially at the operational level). For example, Rethink Robotics organized sessions where the supplier's operatiors learned how to program a robot to which their supply contributed, activity which gave them an outlook on the importance of their work in the final product. A Hardware Startup has to carefully choose not only their suppliers but also their Customers. Rethink Robotics told of the story of a customer that was "fired" due to cultural inadecquacy with the company.	Operational aspect of the business is not an afterthought. Artaic originally concentrated its activities on the Design/Software/Services and Robotics Assembly Business, realizing the importance of operations for mitigation actions only. It is crucial to foster a good relationship with Inbound/Outbound transport suppliers, especially if either the supply or the finished product must comply with tight schedules. These realtionships can be crucial at the time of solving an issue. A Startup must balance carefully cost, quality and schedule, since one of these will have to be sacrificed for the other two. It is relevant to maintain a recorded history of these balances to learn for future case-by-case project conformation (Early hint at Business Analytics)	Understand core value of the company that is being built, and define make versus buy strategic decision. Understand the roadmap of the product you are building Understand the different objectives for the company throughout its evolution Build the products by hand at first and add capabilities to your factory over time. In case eventual factory automation requirements, these can be covered through the income of the company. Supply Chain configuration should be the result of the different forces that influence the specific start-up, e.g., Time to Market, Cost and Quantity of Production

Some of the aspects that were found in the experiences of each of these companies are shown next. Although these aspects were not necessarily mentioned in all interviews, their validity is inferred or all the cases as analyzed, based on the information shared related to other aspects of their strategy and operation. Each of these aspects is described in terms of the System Dynamics terminology, so as to allow their inclusion in the System Dynamics model that is to be derived from the interviews. These aspects are summarized next and explained individually next.

1	Relevance of Founding Team Experience
2	Relevance of Founding Team Networking and Diversity
3	Relevance of Business Vision and Founder's Grit
4	Relevance of Supply Chain as Strategic Pillar
5	Skill set adaptation according to the irreversibility of the strategic decisions
6	Skill set adaptation according to the increasing complexity of the Supply/Operations Process
7	Concentrate of Operational Effectiveness before Operational Efficiency
8	Supply Chain development decisions in accordance with the market conditions for the company
9	Supply Chain knowledge codification
10	Phasing out supply chain related investments according to the developments of the company
11	Balancing Operations according to the Cost-Schedule-Quality Paradigm
12	Organizational Learning

Table 7 - List of Interview Findings Analysis

6.1 Relevance of Founding Team experience

Both in KIVA and Rethink Robotics the background and previous experiences of the team members were determinant in making a timely definition of appropriate business strategies. This evidence agrees with the evidence in the scientific literature, where a new venture with an experienced founding team is more likely to be successful than one that has a less experienced leading team, due to characteristics that may make up for the lack of track record, reputation or resources by the Startup company (Kyung-Moon, 2013; Roure & Keeley, 1990). In the Case of KIVA Systems, Mike Mountz's previous experiences in Webvan and Apple, contributed to a pragmatic product development process, as well as setting clear intermediate objectives for the start-up development. In the case of Rethink Robotics, Jim Daly's previous experiences in related industries contributed to an early definition of an aggressive manufacturing outsourcing process (Sourcing through Customer delivery), and gave the start-up the vision to concentrate on generating the relationships, routines and review processes that would allow this work arrangement to thrive. On the other hand, Artaic concentrated in the processes it considered its competitive advantages, without as yet considering its relationships with its suppliers to the same extent as, for instance, Rethink Robotics (this, even though Artaic has already identified Supply Chain Management as its third strategic pillar).

This has been reflected in literature where focus has largely been shifting from originally considering entrepreneurship as an individual effort, to recent works that propose entrepreneurship should be considered a team effort. Founding teams make strategic decisions together, share ownership, and normally starts as an emerging team, and self-determined membership. Founding Team's abilities have been identified early in management literature, as factors limiting factors for potential growth of the company (Brinckmann & Hoegl, 2011).

6.2 Relevance of Founding Team Networking and Diversity

The breadth and depth of the execution activities were clearly superior in those instances where a diverse team was part of, or closely related with the founding team. This also agrees with empirical studies that relate success to team diversity and networking(Kyung-Moon, 2013). This diversity was expressed either as professional background (PhD level founding teams in KIVA Systems versus PhD/MBA levels at Rethink Robotics, and MBA Level at Artaic LLC) which led to access to professionals from elite research institutions, breadth of experiences in the founding members (KIVA Systems CEO with experience of business failure at Webvan as well as success stories at Apple), and research experience (several of KIVA's co-founders had done intensive research on control structures for robot swarms, and Rethink Robotics' had access to CSAIL's know-how for the development of their robot line).

It is important to note that the original founding teams in each of the analyzed Startups, did not change substantially over time from their original configuration at the start of the business venture.

Since companies can be viewed as a collection of tangible and intangible resources, the management team needs to develop a unique resource configuration over time to assure and maintain competitiveness (Brinckmann & Hoegl, 2011). This finding also agrees with the existing literature regarding the beneficial performance effects of networking for a startup organization.

6.3 Relevance of the Business Vision and founder grit

This characteristic is common to the three cases as analyzed, and consist in a conceptual clarity of the objective that is being sought with the company, as well as the perseverance to drive towards that goal in spite of the problems and obstacles that were encountered. This might be particularly prevalent in Hardware startups, where there is a perception of a higher capital requirement than for that of a start-up in services (Morris, 2014).

6.4 Skill set adaptation according to irreversibility of the strategic decisions

In the cases that were analyzed, two of the companies took opposite decisions, namely to outsource their processes completely (Rethink Robotics) or to maintain all final product production processes in-house (KIVA Systems). Each of these decisions had a different degree of reversibility attached to them. In-house manufacturing considered a higher investment and costs associated with manufacturing and storage facilities, as well as the longer term cost of not constructing closer relationships with their suppliers. This decision might be seen as having a higher irreversibility than the option of an extreme outsourcing, which might lead to an increased exposure to supplier performance. Each of these strategies would consider the choice of different skillsets, and an argument can be made that efficient, relevant relationship management skillsets are more costly to acquire than skillsets for efficient manufacturing and inventory management processes.

6.5 Skill set adaptation according to the increasing complexity of the Supply/Operations process

The processes in the three cases grew in complexity very quickly with the outset of production operations. The complexity in each of these organizations refers to the structural complexity of the organizations, and was reflected as the size of the data that is being managed, number of variables that are required for decision making, number of system constraints within which decisions have to be made, as well as number and type of performance tradeoffs present at the time of making decisions (Manuj & Sahin, 2011). These companies exhibited modifications and adjustments to their Supply Chain Teams, as these were consolidated sequentially roughly through the following key stages: Category Management for the identification of company requirements, Market Review and Identification of Prospective Suppliers, Bidding process and negotiation, Contract Management and Supply Chain Process Development.

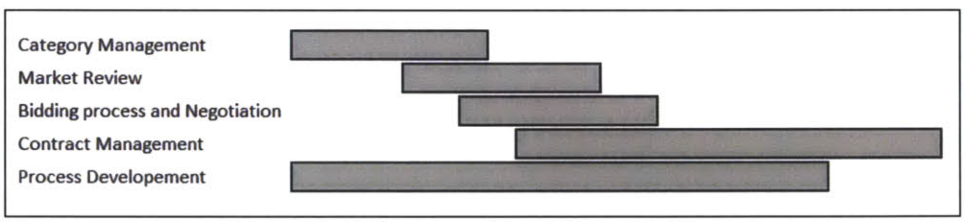

Figure 11 - SC stages requiring skill set adaptation

6.6 Concentrate on Operational Effectiveness before operational Efficiency

The cases analyzed considered some time for setting up and adjusting the Supply Chain process, and obtaining the necessary interaction and regularity with the other functions in the company and partners outside the company, before measures were implemented to improve the process itself. In the case of Rethink Robotics, the performance measurement of their suppliers began only 1 year after the start of their joint operation. According to Daly, performance measurements during the initial operational adjustment phase would have delivered distorted values upon which to base decisions, and would also have diverted resources which were put to better use in other parts of the Supply Chain development process. In the case of KIVA Systems, the Performance measures have not gone beyond basic effectiveness measurements (On Time Delivery, Conformance to Specifications, or Failure Rate) , into what could be considered as an effectiveness-centered performance measurement process, through measures such as effectiveness in the use of resources or process improvement cycles. The measures as described by each of the case studies include some of the characteristics to be found in effective Supply Chain Measurement Systems (Beamon, 1999), and as shown in the following table:

Measurement Characteristic	Characteristic description	Artaic	Rethink Robotics	KIVA
Inclusiveness	**All aspects that are pertinent to the process or system, are considered in the Performance Measures**	Only efficacy aspects were measured, i.e., On time delivery, conformance to specification, quality control.	Both efficacy and some effectiveness aspects were measured, i.e., On time delivery, conformance to specification, quality control, supplier development cycles.	Only efficacy aspects were measured, i.e., On time delivery, conformance to specification, quality control.
Universality	**The aspects being measured allow for a comparison of this measures under different operating conditions**	Performance measures allow for comparison, but do not consider measurement adjustment throughout the supply chain development process phases	Performace measures allow for comparison, but do not consider measurement adjustment throughout the suppy chain development process phases	Performace measures allow for comparison, but do not consider measurement adjustment throughout the suppy chain development process phases
Masurability	**The data which is required for the performance indexes, can be readily measured from the process**	Measurements Possible. Measurments Inhouse, Basic records kept	Measurements Possible. Many of the measurments are done by the Main Implementation Supplier.	Measurements Possible. Measurement Inhouse
Consistency	**The Measures being obtained are consistent and aligned with the organizational goals**	Alignment exists as measurements aid process efficacy	Alignment exists as measurments aid Supplier involvment and Rethink Robotics' peripheral involvement in supply process	Alignment exists, as measurements aid to quick product development cycles and increasing supplier involvement as product line is more mature.

Table 8 - Performance Measurement Characteristics

6.7 Supply Chain development decision-making according to particular market conditions for the company

Although only KIVA Systems' CEO mentioned this aspect explicitly in their start-up learnings, all three of these successful Start-ups showed an adaptation to their particular market conditions, privileging their strengths for the construction of an increasingly robust supply system. Rethink Robotics privileged its founder's leverage to form convenient supplier relationships while developing a technically strong product; KIVA devoted quite a long time to generate a product along a well-thought-out product development path, issuing patents along the process as required, and benefiting from the early involvement of a skillful team, leading to the publication of articles related to KIVA Systems' proposal in specialized journals and magazines, as well as the generation of several pilot test runs.

Physical proximity to a University has also been documented as an aspect related to tech startup success, such as in the case of all three analyzed cases, having a positive relationship with firm growth (Helmers & Rogers, 2011).

6.8 Supply Chain knowledge codification

In all case studies analyzed, the team initially focused on efficacy and thereafter on effectiveness of the supply process. All interviewees mentioned the codification of knowledge as a relevant stage during the effectiveness development of the process, consisting on the internalization by the company of knowledge held by individuals. In the case of Artaic, this process was being achieved through the specialization of the members in the team so as to minimize the exclusive knowledge one single member has, and through the rotation of team members through different roles and activities so as to have more members having knowledge and experience in different parts of the operation. Rethink Robotics codified the knowledge of its workers through the generation of detailed procedures.

Another important aspect related to the codification of knowledge, found in all the analyzed cases, was the use of Patents as a way of securing the knowledge that was being developed within each organization. This process is indicated in literature as having a direct effect on asset growth of tech startups, allowing for increases between 8 and 27% in their annual growth, as well as extended startup survival rates and total investment received (Helmers & Rogers, 2011).

6.9 Phasing out supply chain related investments according to the development of the company

This aspect was mentioned by Mountz from KIVA Systems, and is considered a key aspect in the development strategy that KIVA has followed while developing its product line. Mountz's previous experience in Webvan made his decisions especially sensitive to these aspects of synchronicity between business development / growing revenue, with the development of physical installations for Sourcing, Storage, Production and Delivery processes. In the case of Rethink Robotics, the investment in production facilities was not considered in the initial strategy, which relied heavily on the available production capacity at the main implementation contractor, and this supplier's eventual strategic decisions to expand capacity if required. This aspect was not identified as strategic in the case of Artaic, since the initial investment in the robotic arm for pick and place activities could not be deferred, and instead, the deferred investment was seen in terms of team configuration and expansion of warehousing and production facilities.

6.10 Balancing of operations according to a Cost-Schedule-Quality paradigm

The Development of the Skills by the company was portrayed to be a delicate balance between opposing forces, which demand continuous monitoring from the existing team and timely decisions from the staff. One of these balances considers a tradeoff between Cost, Schedule and Quality of the service that is being provided by the supply function.

Following the main findings that were analyzed from the interview results, some key aspects were identified, which influenced the Supply and Operational Skills development within a startup. These Aspects considered as relevant factors,

- Team experience: broader concept which contains the founding team's previous work experience, as well as existing team networking
- Existing team diversity: constituted by the diversity of factors which contribute to a heterogeneous assessment of situations and search of potential solutions to problems
- Project Quality: considered as the application which is being developed as well as the cultural considerations in process quality which can be found in the existing team
- Access to Relevant Technology: considers the environment where the technological advancements happen, this is, the existing companies, clusters and resources available to develop the product
- Product Development Cycle time: characteristic which considers the supply network, Development Cycle Times and which is a measure of the interaction with the engineering departments), and finally
- Participative Product Development process: accounts for the processes and procedures existing with other members of the supply chain which allow for the timely coordination of product development cycles.

These aspects are shown in the next diagram.

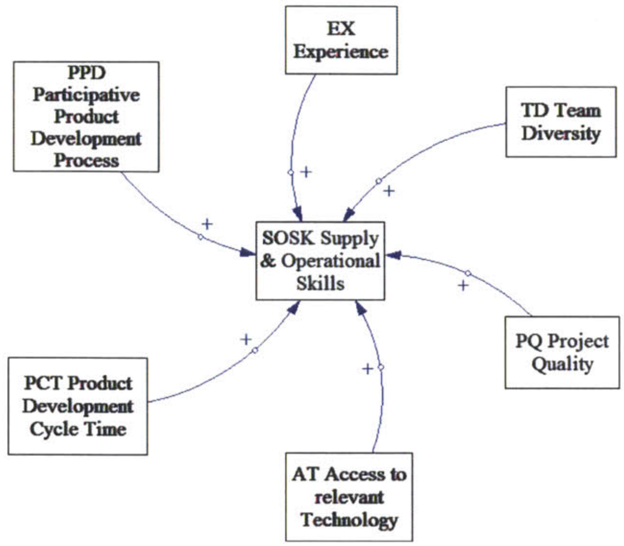

Figure 12 - Main Aspects for Skills Development

7 System Dynamics methodology

System Dynamics, born from the Systems Engineering discipline in the 1950's, is the method by which complex systems can be modeled through a network of causal relationships between appropriate system variables, and making use of specific key main elements (i.e., Stocks, Flows, Delays and Auxiliary Variables) to display the dynamic behavior of the system (i.e., behavior over time) including the effect of feedback loops resulting from these dynamic interactions.

Well-designed System Dynamics models will deliver non-intuitive insights for a system, are not limited to a mere system description, but will assume sensible values for characteristic system parameters delivering a resulting behavior for the key variables of interest. This may throw light on previously puzzling behaviors of those key variables. It is also a team effort. In words of Jay Forrester, creator of the discipline,

> *"..to be effective, models should become part of a more persuasive communications process that interacts with people's mental models, creates new insights and unifies knowledge.."(Forrester, 1986)*

People in general tend to understand events in terms of linear causal chains instead of networked causal loops of several related variables (Vennix, 1996). Some of the effects of this is that people are inclined to concentrate on parts rather than wholes, and connections between different parts of a system are not considered or its effects are minimized.

The Feedback nature of Human Systems cannot be overstated, given that all learning depends on feedback. Careful reflection will show, that all we know of our behaviors are the feedbacks of our own outputs (Sterman, 1994).

Some complex problems have been defined as messy problems (Vennix, 1996) since they generate different opinions among observers, first, on whether there is a problem, and if there is an agreement on the problem's existence, then on what the problem actually is.

Several approaches have been proposed to determine the suitability of System Dynamics methodology application and, although there is a wide variety of approaches to the formation of a System Dynamics model, there is academic literature on best practices identified for the discipline, pointing out practices and recommendations that range from those concepts where there is a high degree of consensus, to those where there are opposite ways of implementing the methodology (Martinez-Moyano & Richardson, 2013).

7.1 Hardware Startups modeling through System Dynamics

Scientific literature has suggested that Entrepreneurship should be treated as a Systemic Phenomenon, to include Area-level Infrastructure, Policies and Institutions for understanding the Entrepreneurship behavior of a specific region, e.g., a city, a region or a country. This is also pointed out as relevant at the time of evaluating the factors that determine the community's ability to generate, foster and promote technological transfers by Startups, as products to the market (Ács et al., 2014).

Some distinguishing characteristics of the systemic approach to understanding Entrepreneurship systems, are the imperfect substitutability of its constituent parts, potential bottleneck factors that hinder the system from optimum performance, and required coevolution of population-level processes (i.e., attitudes, abilities and aspirations), and the Institutional Context where these processes take place.

Indexes for Entrepreneurship Development have also been proposed in the scientific community, such as the Global Entrepreneurship Development Index GEDI (Ács et al., 2014), the Kauffman Index of Entrepreneurial activity[39], or the Entrepreneur's Index by Barclays[40].

System Dynamics models have been proposed for analyzing the development of new areas within small and medium companies, such as their incursion into e-commerce (Bianchi & Bivona, 2002), Technological innovation within entrepreneurial teams (Wu, Kefan, Hua, Shi, & Olson, 2010), and Project Management (Lyneis & Ford, 2007), of which the latter holds the most promising tools for application into new Hardware Startups if viewed as Projects for the for Idea-to-Market process, at least for its process components.

The System Dynamics Modeling approach that will be used for this research will follow John Sterman's proposed method, which divides the process into 5 steps, namely Problem Articulation or Boundary Selection, Formulation of a Dynamic Hypothesis, Formulation of a Simulation Model, Testing, and Policy Design and Evaluation. These steps are not normally linear and the overall process is iterative(Sterman, 2000).

Although system mapping is a crucial aspect of the model generation, some authors indicate keeping the model on that stage only, without going into simulation, can lead to over inference and failure to explore sensitivities and Dynamic Hypothesis adequacy. (Homer & Oliva, 2001).

The model that will be developed in this section, which is a model before the analysis of the Interview results, is a Qualitative Model with some quantitative sections. The conclusions will indicate future areas of development for this model.

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[39] http://www.kauffman.org/what-we-do/research/kauffman-index-of-entrepreneurial-activity

[40] https://wealth.barclays.com/en_gb/home/wealth-management/who-we-help/entrepreneurs/entrepreneurs-index.html

7.2 Model Development Strategy

Jay Forrester did not indicate a specific way in which the System Dynamics Modelling should be implemented, and there are many ways in which System Dynamics practitioners represent the heuristics they use. The literature in general agrees that it is an iterative model and contains at least the Conceptualization, Formulation, Testing and Implementation stages somehow represented in their processes. The following table shows the main approaches to System Dynamics modeling (Randers, 1980; Richardson & Pugh, 1981; Sterman, 2000):

Randers (1980, p. 119)	Richardson and Pugh (1981, p. 16)	Sterman (2000, p. 86)	This study
Conceptualization	Problem Identification and Definition	Problem Articulation (Boundary Selection)	Problem Identification and Definition
	System Conceptualization	Formulation of Dynamic Hypothesis	System Conceptualization
Formulation	Model Formulation	Formulation of a Simulation Model	Model Formulation
Testing	Analysis of Model Behavior	Testing	Model Testing and Evaluation
	Model Evaluation	Policy Design and Evaluation	
Implementation	Policy Analysis		Model Use, Implementation, and Dissemination
	Model Use or Implementation		
			Design of Learning Strategy/Infrastructure

Table 9 - Approaches to System Dynamics Modeling (Martinez-Moyano & Richardson, 2013)

In this specific work, we will follow the methodology as proposed by Sterman, so we will proceed to articulate the problem to thereafter propose a Dynamic Hypothesis to eventually propose a formulation for the Simulation Model. This work will not venture into testing the model, although some policies will be extracted from the Model Formulation, proposals which would need subsequent testing, arena for some future work.

7.3 Problem Articulation

Hardware Startups have success rates which are affected by their capacity to synchronize their Supply Chain and Operational Needs with what is required of their current business structure and market expectations. The inability to react adequately to this adaptation may lead them to either:

- An overqualified team, which would have repercussions in the cost structure of the Startup as well as the motivation of the team, who may feel underutilized and therefore promote labor force attrition, or
- An underqualified team which would render the organization unable to react to changes in the operating conditions through e.g., unforeseen required prototype cycle times, or spikes in product demand.

It is therefore sensible to seek a greater understanding between the systemic forces that exist and interact within a Startup during this period of growth and co-evolution of organization vs. requirements, with the aim of identifying adequate policy levers within the company or within the industry that will optimize this coevolution process.

7.4 Formulation of Dynamic Hypothesis

The Dynamic Hypothesis will center on the system structure that will keep the Available Team Skill Profile in a balance with respect to the desired Skill Profile. There are forces that counteract the possibility of a Startup team becoming too overqualified, or too underqualified, which balance the way in which the Startup will manage the level of available skill within its team.

7.5 Formulation of Simulation Model

First we will introduce the basic deviations present in the model, this is, skill level and Labor Force, to then analyze the Reinforcing Loops and Balancing Loops present in this simple approximation to the system.

7.5.1 Deviation for Required Skill Level

Over-qualification can be described as the divergence from a desired level of qualification or skill. For now we will consider the desired level of skill as exogenous, as an input to the system. This desired level of Qualification can originate from an expectation from the Founder Team or an expectation from the market, as reflected e.g., in the level of skill a Purchaser must have at the stage of negotiation contracts. This Qualification/Skill divergence is shown in the following diagram:

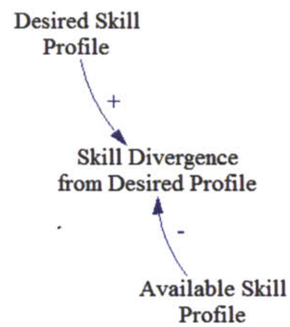

Figure 13 - Divergence from Desired Skill Level

And would take the following Equation:

$$DISKP = AVSKP - DESKP$$

DISKP = Divergence from Desired Skill Profile
DESKP = Desired Skill Profile
AVSKL = Available Skill Profile

7.5.2 Labor Force Change

Hiring is a process that takes place as a response to Organizational requirements concerning roles that have to be filled and a specific Skill Profile to which these roles must comply. The Hiring process must take place as a function of the required positions and skill profiles sought, as well as to the available budget. Hiring rate will be inversely related to the available Budget (the less budget there is, the less hiring that will take place, all else equal), positively related to the number of roles sought (the more the number of Desired Labor Force, the higher the Hiring rate will be), and negatively related to the Skill Profile level sought, this is, the higher the skill level sought, the slower the Hiring rate will be, since professionals that are highly qualified, or that comply to a narrow set of criteria, are harder to find in the market.

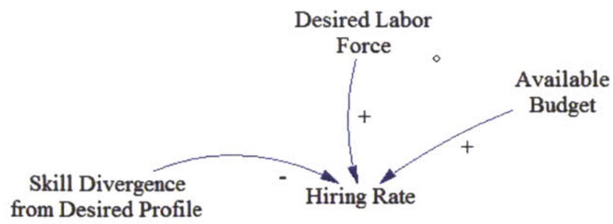

Figure 14 - Hiring Rate Influencing Factors

Additionally, this Hiring Rate will be a function of time, since the Hiring process will not be immediate. The usual way of modeling a Hiring process is by creating a Stock for the Labor Force that will have a 1st Order Delay to reach asymptotically the Desired Role Count. Since the Skill Divergence will affect the Hiring process time, it will be an input into the Labor Adjustment time, increasing this time if the Skill Gap is Bigger.

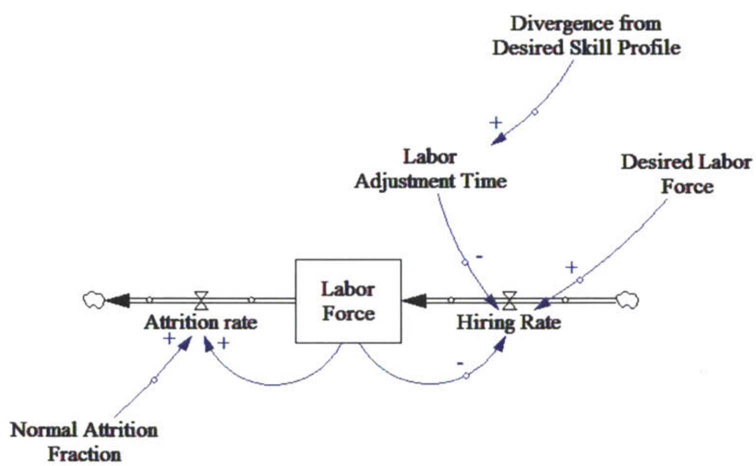

Figure 15 - Labor Adjustment Flow Diagram

HR = (DLF – LF)/LAT
AR = LF * NAF
LAT = NAT * DISKP

HR = Hiring Rate
AR = Attrition Rate
LAT Labor Adjustment Time
DLF = Desired Labor Force
LF = Labor Force
NAF = Normal Attrition Fraction

7.5.3 Balancing Feedback Loops for Available Team Skill Profile

Balancing Feedback Loops are systemic effects (causal chains) which, upon an increase in a variable deviation from a required target value, will structurally promote a reduction of that deviation towards the target. In our case this means analyzing the structure of our system for ways in which an increase in the deviation from the required qualification/skill level of the team, will trigger a causal chain that will result in the reduction of this qualification/skill deviation. Two basic mechanisms are therefore proposed.

One mechanism is budgetary. Looking at the Feedback loops present, it can be argued that in case a team was overqualified (as a result of a careful Hiring process), this is, the Skill Profile Divergence is positive, this would have an effect on the Staff operating costs since, all else equal, a more skilled team tends to be more expensive to maintain. The Hiring would stop and the natural team attrition would bring the team back to the desired level. The only case where the team would be purposely downsized (i.e., employees would be terminated), would be because of Budget reductions and not because of Skill Profile Divergence. In strictest sense, a startup would benefit from all the surplus skill until the attrition leveled off the skill to the balance level due to Natural Attrition.

The other mechanism is motivational. If the team is overqualified for the skill level as required by the activities of the organization, an argument can be made that, all else equal, the team will have an attrition level higher than the standard attrition rate for the industry, and resulting from highly skilled individuals looking for professional challenges in other companies. This effect would lead to the Available Team Skill Profile returning to the desired level.

7.5.4 Reinforcing Feedback Loops for Available Team Skill Profile

Reinforcing Loops are systemic effects which, upon variation of a variable, will structurally promote the further continued variation of this variable. In our case, it means analyzing ways in which a deviation of the Available Team Skill Profile from the Desired Team Skill Profile will trigger a causal chain which will promote further deviation from this required level. The basic mechanism for such an effect is proposed as market related. If the Labor Force was overqualified, it would result in a higher available team flexibility. The team would then be able to have better reactions to unforeseen changes in work demand, due to a higher Response Rate to Changing Context Conditions. This higher response rate would then lead to increased commercial success which would have a positive effect on available budget and therefore readiness to continue hiring. This corresponds to a Reinforcing Feedback Loop which has been graciously named "Success to the Successful", and is shown next:

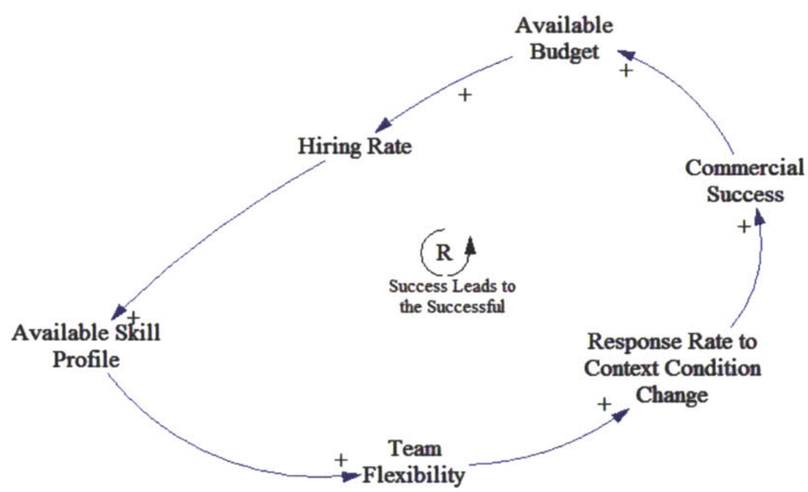

Figure 16 - Success to the Successful Reinforcing Feedback Loop

Normally team Flexibility is a manifestation of team adaptability and malleability expressed through shorter learning curves and the smaller effects of customer input disruptions on team performance (i.e., reduced level of amplification) . This would be a function of the Available Skill Profile and of the standard Team Flexibility found for similar teams in the industry. A Similar effect can be used to model the Response Rate for the Context condition Change, i.e., through the comparison of a Standard Rate of Response to Context Condition Change. In case of the Commercial Success, this is not necessarily bound by a Standard commercial Success, since this threshold can change in comparison to the response to Context Condition Changes by other actors in the Industry.

The following Diagram shows the Feedback loops as described in their overall view of the proposed interaction:

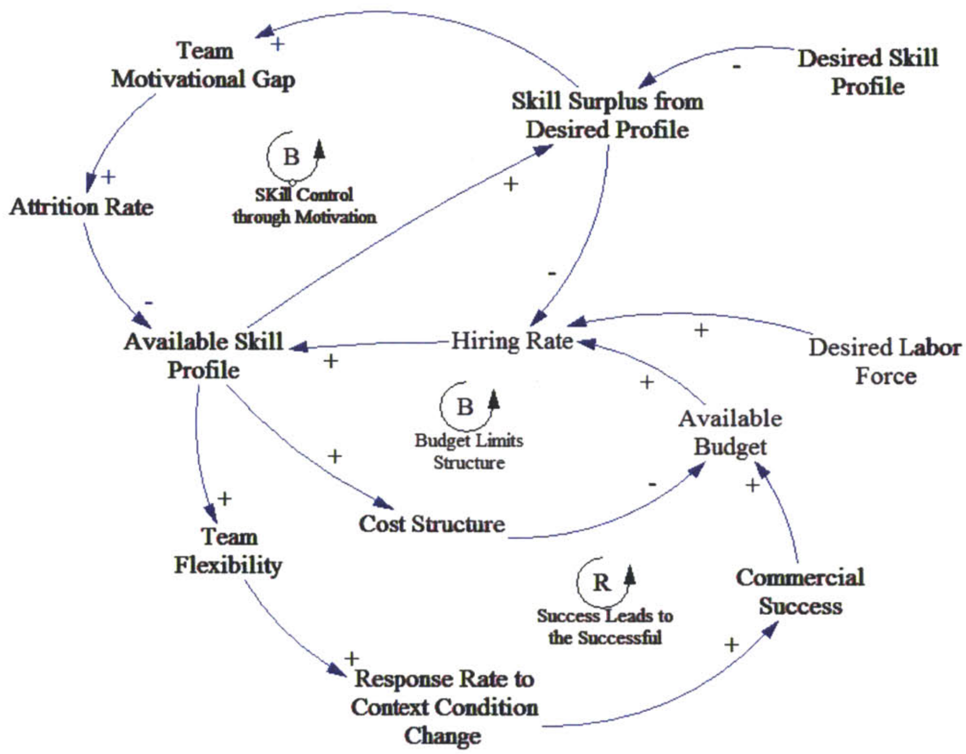

Figure 17 - Overall Casual Loop Model

8 System Dynamics Model Adjustment and Analysis

The System Dynamics proposed model analysis will be separated in two sections. In the first of these, an analysis of the model proposed in section 7 (denominated "Required versus Available Skill Balancing Model") will be carried out by contrasting the model structured as described in that section with the evidence gathered thorough the interviews. The main aspects that were obtained from these experiences will be reflected in an adjusted, albeit qualitative, model.

The second part of the analysis will consist of a contribution towards the "Nail-it!" Startup Framework proposal by professor Dr. Charles Fine, as developed for a first draft of his "Operations for Entrepreneurs" course at the Massachusetts Institute of Technology, (Fine, 2013). The model seeks to reflect the process starting with the Product Concept which is refined through a series of dynamic loops, resulting in a prototype/early production which is ready to be scaled. Some of the findings in the interviews will add to that existing model.

8.1 Required vs Available Skill Balancing Model

The basic model for Skill development is shown in Figure 17. In order to complement this model with the findings from the interviews, a structured analysis was made regarding relevant causal loops which might not have been included in the initial model. These proposed adjustments are summarized in the following table, where each of the aspects discussed in the summary of the information acquired from the interviews is analyzed through the lens of the proposed model, where either Reinforcing Loops, Exogenous Factors or Coevolution Structures are proposed as additions to the model.

		Original "Required versus Available Skill Balancing Model"	
Finding Description	**Description of Influence**	**Potential Basic implem.**	**Main Associated Causal Loop / Exogenous Factor /Coevolution**
Relevance of Founding Team Experience	Founding team experience conditions paradigms to be used in business development.	Yes	Exogenous factor - Founder team experience conditions reaction time to changing conditions which will influence hiring times
Relevance of Founding Team Networking and Diversity	Networking and diversity will allow a broader search for potential for business partners, and innovative product development	Yes	Reinforcing Loop - A broader network will influence in the Hiring Rate, which will influence the Available Team Skill profile. This available skill profile will influence the dimension of the available skill, generating a Reinforcing Loop.
Relevance of Business Vision and Founder's Grit	The ability that is perceived in the organization that generates resilience and adaptation	No	
Relevance of Supply Chain as Strategic Pillar	Supply Chain is an aspect that has to be considered from the beginning of the endeavor	No	
Skill set adaptation according to the irreversibility of the strategic decisions	Consider riskier adaptations according to the irreversibility of the decisions that are made.	Yes	Exogenous factor - Irreversibility of decisions will condition the desired team skill profile, which will influence the gap that exists with the actual team skill profile.
Skill set adaptation according to the increasing complexity of the Supply/Operations Process	Consider the Complexity of the operations when determining the skill adaptation required.	Yes	Exogenous factor - increase in operations complexity will influence the desired team skills profile, and thus the gap that exists with the actual team skill profile.
Concentrate of Operational Effectiveness before Operational Efficiency	Focus on getting things done in a nescient business, before concentrating on using the resources efficiently	No	
Supply Chain development decisions in accordance with the market conditions for the company	Supply Chain decisions should consider the relative strengths of the company that can leverage better decisions	Yes	Exogenous factor - Market conditions will influence the Desired Skill Profile
Supply Chain knowledge codification	Reflect knowledge as an organizational property and not only a property on to individuals.	No	
Phasing out supply chain related investments according to the developments of the company	Generate investments sequentially and in coevolution with Organizational Complexity	Yes	Coevolution of Company complexity growth and Supply Chain available skills
Balancing Operations according to the Cost-Schedule-Quality Paradigm	Consider aspects of Cost, Quality and Schedule when evolving the Supply Chain skills	Yes	Cost, Quality and Schedule will influence Desired Skill Profile
Organizational Learning	Iterations of a process will have an effect on the organizational knowledge of the process and will influence effectiveness and efficiency of future process iterations	Yes	Team Flexibility will have an increasing effect on the response rate of the context condition change., which will lead to increased organizational Flexibility.

Table 10 – Proposed adjustments to original basic model

These adjustments have been added to the following diagram, where the new links are indicated through dashed-line links.

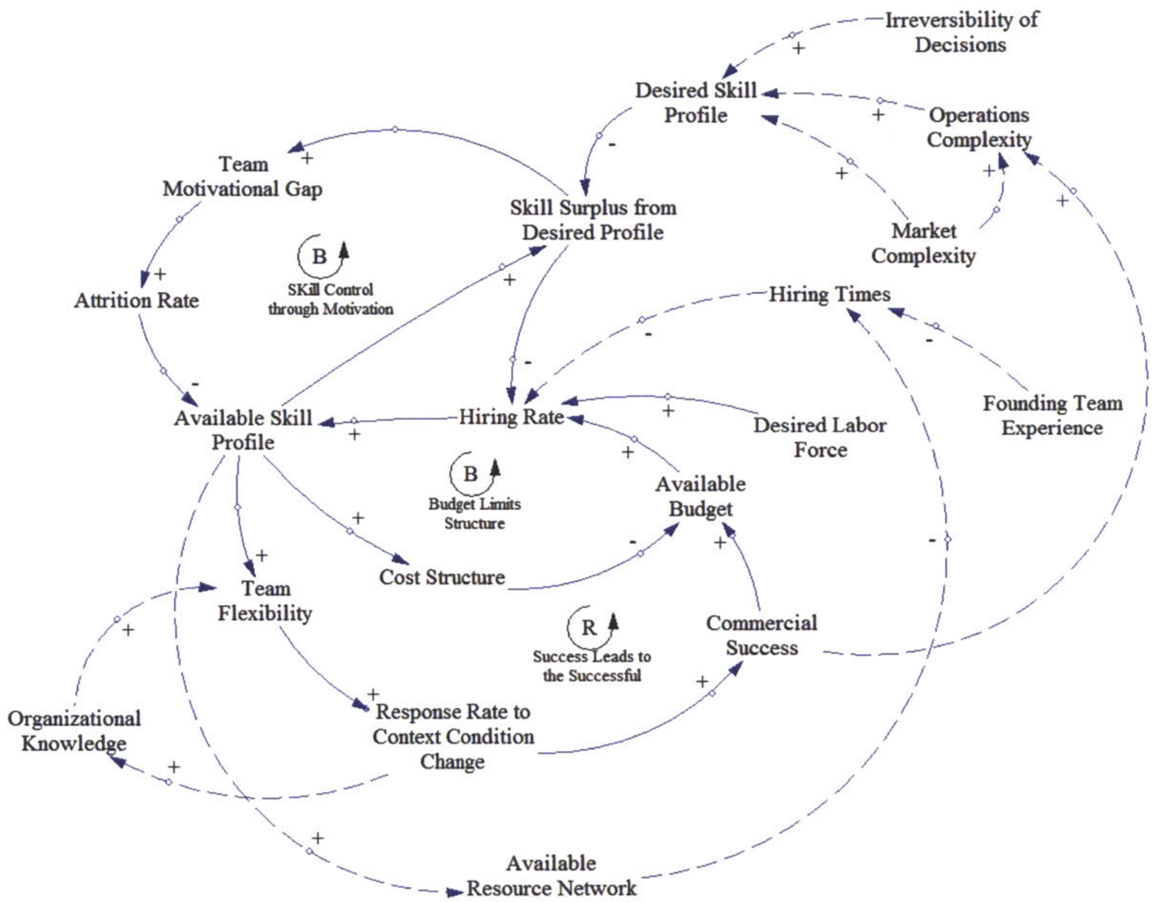

Figure 18 - Adjusted System Dynamics Causal Model

The resulting dynamics in the system is a continuous adjustment in the Available Team Skill Profile to account for sufficient but not excessive team size, as long as the organization is able to fund it, and depending also on the required response times, requirement where greater team size is desirable for quicker response.

Desired Skill profile is driven my environmental conditions including Market complexity, Operations complexity and the irreversibility of the strategic decisions that are made inside the organization. The Hiring times, which is actually the response time to comply with the required Team profile, is determined by Team experience which will influence the standard Hiring time for the specific industry.

On the other hand, Organizational flexibility will feed on the knowledge acquired from the existing flexibility and its prompt use in managing changes in the context conditions. This virtual cycle is a reflection of organizational learning, where each subsequent iteration in the process of facing context changes, should deliver an increase in organizational knowledge available to face the next upcoming context change. This increase is however marginally decreasing, and potentially asymptotic to the maximum flexibility potential of the available group.

8.2 Nail it, scale t, Sail It model contribution

The model, as proposed by Charles Fine, is reflected in Figure 19 (Fine, 2013). The structure of the system consists of a series of causal loops that in broad terms reflect the initial search for appropriate concept ideas, which once reflected as an initial prototype, are exposed to the Innovator's Customers. This is an iterative process, since the result of this communication leads to corrective actions, such as an adjustment of the team, the refinement of the product concept and the subsequent construction of a refined prototype, the search for other innovator customers which may be more aligned with the product concept, or the decision to show the current state of development of the concept to investors.

When the Feedback that is received complies with a target metric, the product can be scaled.

This first approximation captures some very relevant aspects of the initial idea development for Hardware Startups However, from the analysis of the information from the Interviews, several aspects are detected which may add to the model, since it does not mention the aspect of Operations/Supply Chain Skill Development within such an organization.

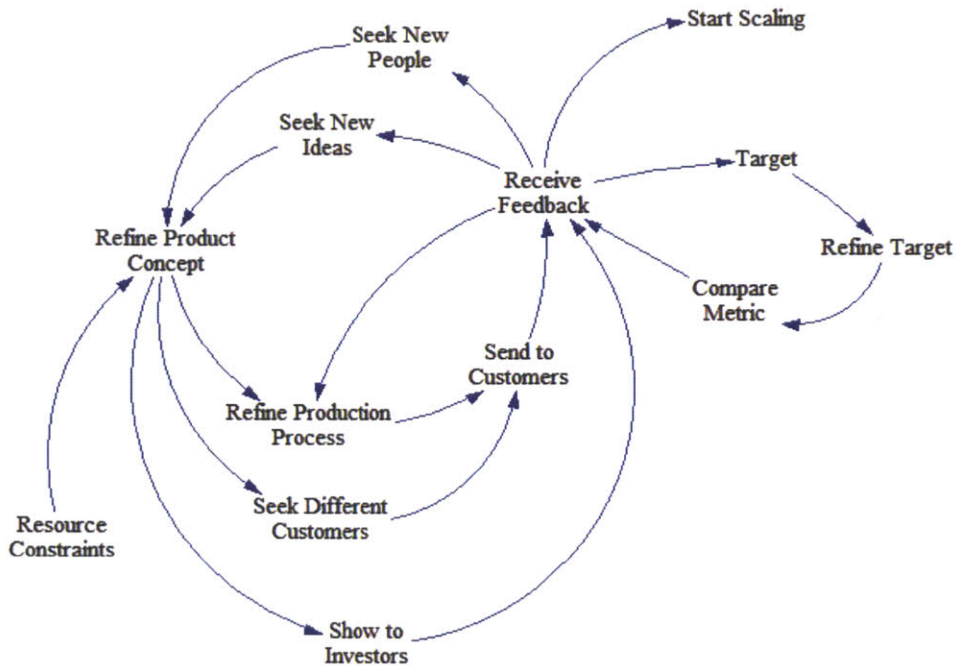

Figure 19 - Nail-it stage base Causal Loop Diagram

Upon making an initial analysis of the existing Nail-It! Model, several aspects present in literature were identified as areas for complementing the model. Literature has identified crucial aspects in hardware startups regarding Founder Team vision (Kyung-Moon, 2013), Team Diversity and Relational Capabilities (Brinckmann & Hoegl, 2011), Technological Transfers and Funding Characteristics (Heirman & Clarysse, 2004), as well as Product Development Cycle Times and Supplier Relationship Forging and maintenance (Cousins, Lawson, Petersen, & Handfield, 2011). These aspects were added to an initial modified Nail-it! Model, as shown in Figure 20.

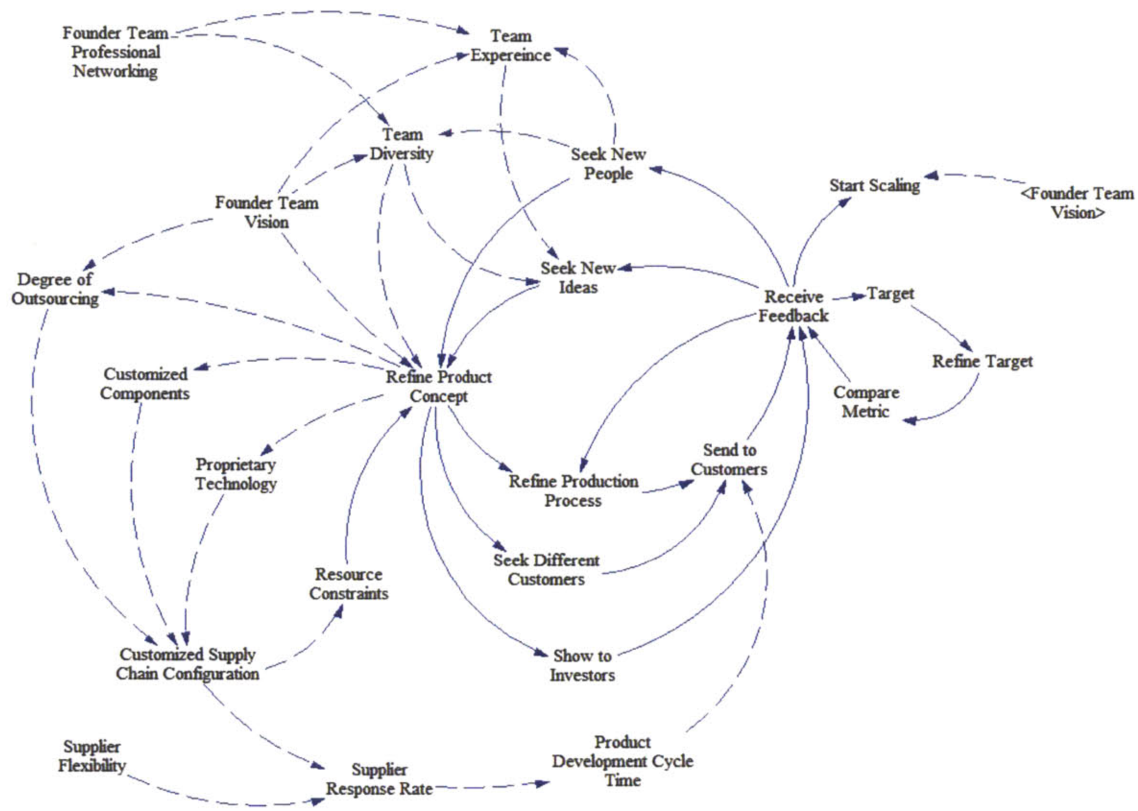

Figure 20 –Initial Additions to System Dynamics Causal Model for Nail-It stage of Startup Development

Some notable feedback loops have been added, namely the Outsourcing loop as a source of decreasing resource constraints, as shown by the red, dotted links in Figure 21, the proprietary technology loop decreasing constraints for resource usage which is derived from own technological developments within the Startup, as shown by the red, dotted links in Figure 22, and the Customized Components Loop, which will affect supplier availability as shown by the red, dotted links in Figure 23, either by capturing a supplier who will produce components that are highly specialized, or by making it difficult to find suppliers who will be willing to manufacture customized components.

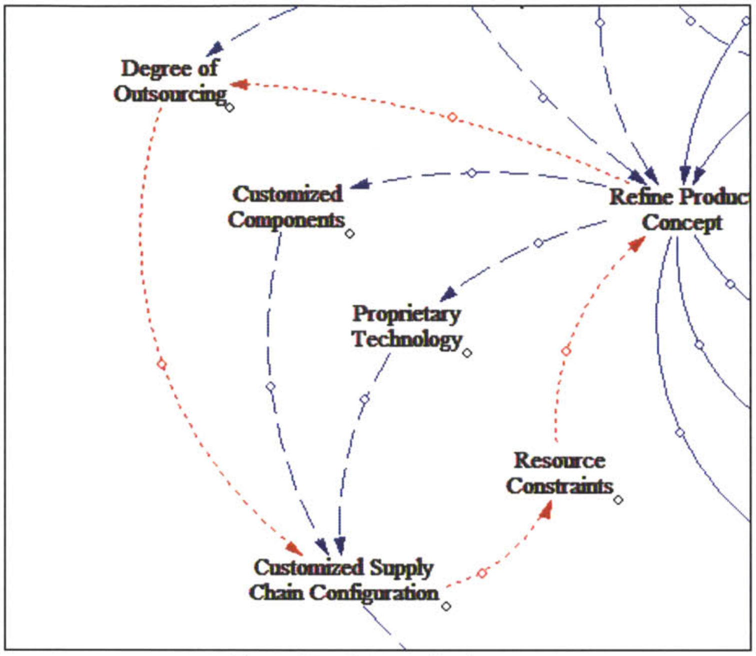

Figure 21 - Outsourcing Loop

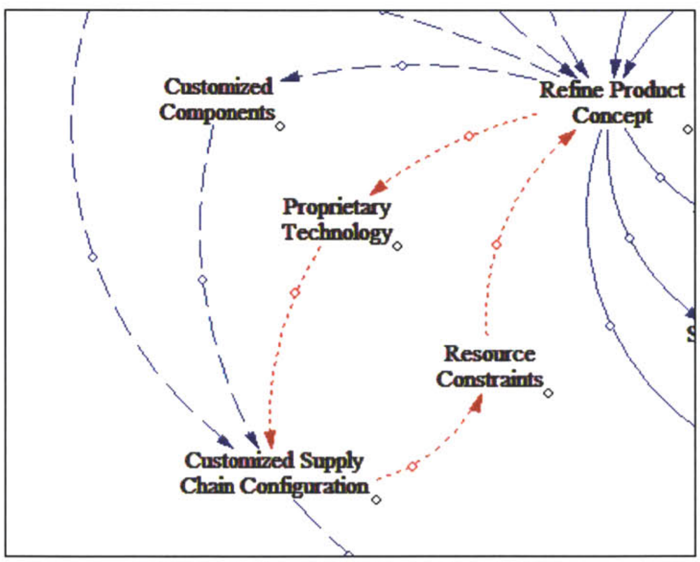

Figure 22 - Proprietary Technology Loop

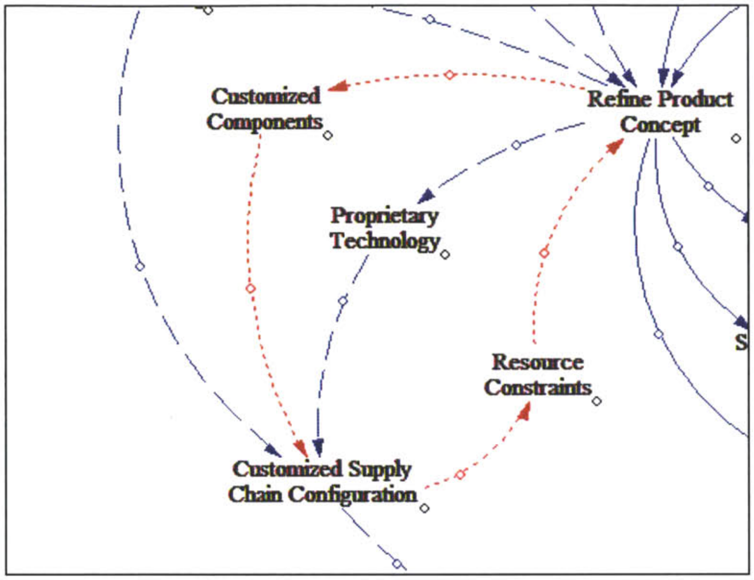

Figure 23 - Customized Components Loop

Additionally, a loop was identified which will allow for a fundamental aspect of product development cycle time, which is the supplier response rate, as shown in the red, dotted links in Figure 24.

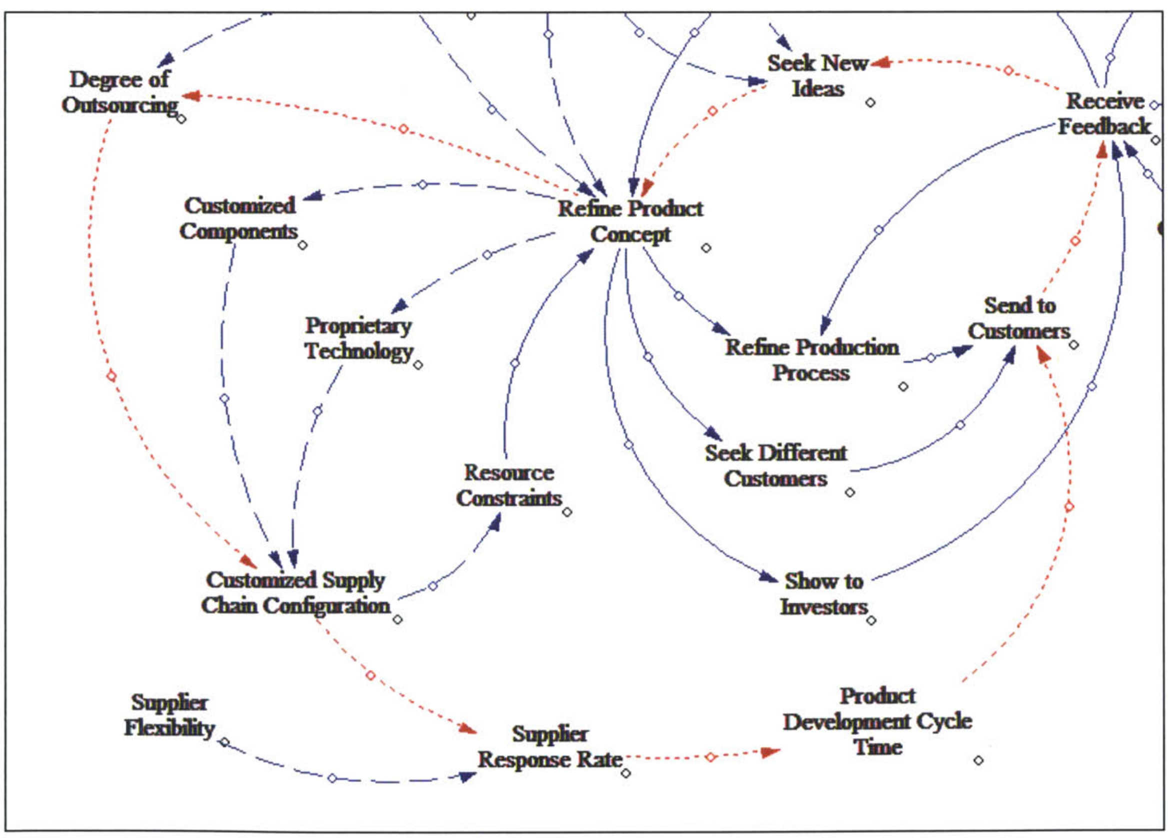

Figure 24 - Supplier response time loop

An analysis of the main aspects found in the interviews, and the potential adjustments to the model have been summarized in the following table:

		Nail it! Model	
Finding Description	**Description of Influence**	**Potential Basic implementation**	**Main Associated Causal Loop / Exogenous Factor /Coevolution**
Relevance of Founding Team Experience	Founding team experience conditions paradigms to be used in business development.	Yes	Already included in the Initial Additions to the Nail it! model as influencing the search for new ideas
Relevance of Founding Team Networking and Diversity	Networking and diversity will allow a broader search for potential for business partners, and innovative product development	Yes	Already included in the Initial Additions to the Nail it! model as influencing team diversity and team experience
Relevance of Business Vision and Founder's Grit	The ability that is perceived in the organization that generates resilience and adaptation	Yes	Already included in the Initial Additions to the Nail it! model as influencing team diversity, the refinement of product concept, as well as the degree of outsourcing required in the business, as a strategic decision.
Relevance of Supply Chain as Strategic Pillar	Supply Chain is an aspect that has to be considered from the beginning of the endeavor	No	
Skill set adaptation according to the irreversibility of the strategic decisions	Consider riskier adaptations according to the irreversibility of the decisions that are made.	No	Potential Application for the Scale it! phase of Startup development
Skill set adaptation according to the increasing complexity of the Supply/Operations Process	Consider the Complexity of the operations when determining the skill adaptation required.	No	Potential Application for the Scale it! phase of Startup development
Concentrate of Operational Effectiveness before Operational Efficiency	Focus on getting things done in a nescient business, before concentrating on using the resources efficiently	Yes	Already included in the Initial Additions to the Nail it! model process of product refinement without considering efficient use of resources until the Sail it! Phase.
Supply Chain development decisions in accordance with the market conditions for the company	Supply Chain decisions should consider the relative strengths of the company that can leverage better decisions	Yes	Already included in the Initial Additions to the Nail it! model as the feedback loop that considers the customer input through product development
Supply Chain knowledge codification	Reflect knowledge as an organizational property and not only a property on to individuals.	No	Potential Application for the Sail it! phase of Startup development
Phasing out supply chain related investments according to the developments of the company	Generate investments sequentially and in coevolution with Organizational Complexity	No	No consideration in the model about investment phases
Balancing Operations according to the Cost-Schedule-Quality Paradigm	Consider aspects of Cost, Quality and Schedule when evolving the Supply Chain skills	Yes	Already included in the Initial Additions to the Nail it! model as the feedback loop that considers the customer input through product development
Organizational Learning	Iterations of a process will have an effect on the organizational knowledge of the process and will influence effectiveness and efficiency of future process iterations	No	

Table 11 - Proposed Adjustments to the Nail It! Model

9 Conclusions

The conclusions will be presented in two sections. The first section will talk about the Proposed Guidelines for Startups in relation with their Supply Chain and Operations development strategy, as derived from the analyses done throughout this work. The second section will indicate future areas of research which can be derived from this work.

9.1 Proposals and Guidelines

Startups are organizations which learn and evolve under restricted resources, and taking advantage of the uncertainty avoided by established companies as fertile ground for the proposal of new ideas. This resource restriction is further constrained by the enormous amount of available guiding material, albeit mostly in the areas of product development and commercial strategic management. It is therefore essential that whichever guidelines might be proposed to Startups on ways to better prepare for the Supply Chain requirements their endeavor will require, should be relevant and concise and oriented towards direct application.

Thus, one important last task in this work is to show the summarized reflection of the insights and learnings that have been gathered through the interviews contained in this work, as well as the bibliographic research and the analysis made on the information that was collected.

From the information that was gathered, the practical implications to a nescient endeavor can be viewed through the Be-Do-Have/Achieve Paradigm, which reflects a compelling way of looking at the pre-requisites for achieving goals, as applicable to startup companies.

Figure 25 - Be-Do-Have-Achieve Paradigm

The learnings are summarized in the following diagram according to the stage of the paradigm realization where they are suggested to fit the most:

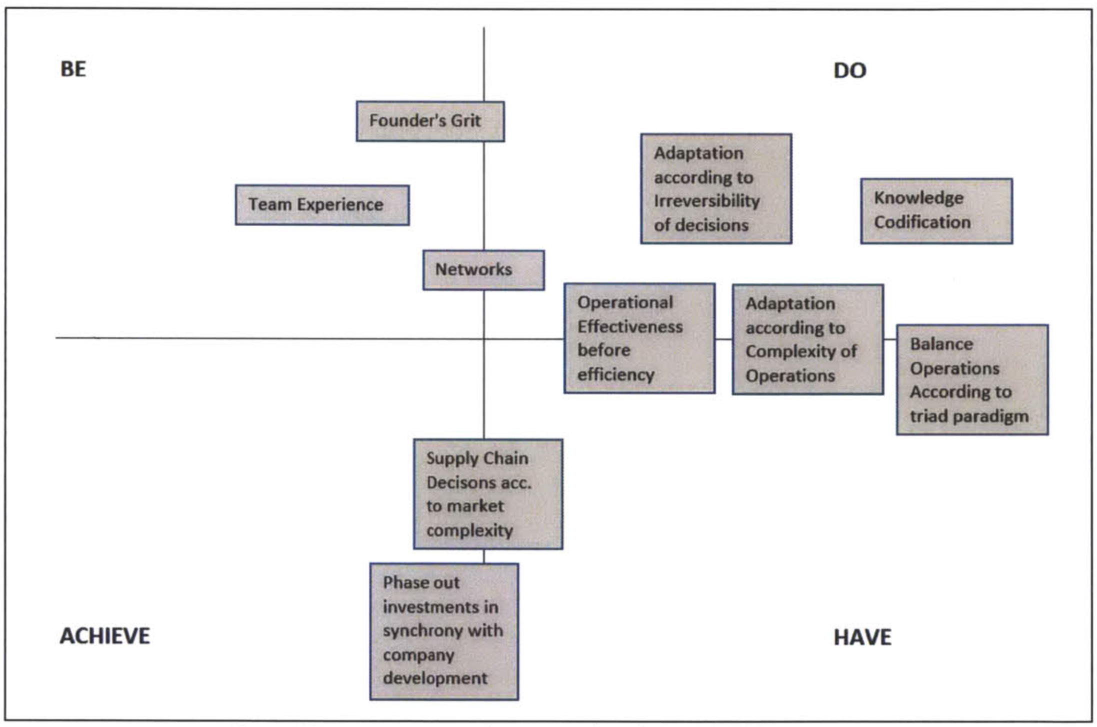

Figure 26 - Be-Do-Have-Achieve Paradigm learnings Arrangement

9.2 Future Areas of Research

The main areas of future research which have been identified from this work are:

- **Further interviews to Startup companies within the robotics industry**, ideally with a scope of interviewing both successful and unsuccessful companies. The bias that is obtain by only looking at successful companies necessarily does not allow for a complete consideration of the factors that led to the success. Information as gathered from the successful can lead to erroneous assumptions of causation, when there might only be a correlation of factors. A specific factor might just have happened to be present in a couple of successful company, yet it might also have been present in unsuccessful companies. Additional observations from the point of view of the unsuccessful will allow the differentiation of those factors that might have causation on success.

- **System Dynamic Models for startups should be extended in their causal descriptions**. These causal descriptions might explore aspects different than the building up of Supply Chain and Operations capabilities, and might delve into aspects such as supplier development strategies, formulation of strategic decisions, or risk analysis versus irreversibility of decisions.
- **System Dynamics Models should be extended towards quantitative models**. This extension will allow for the exploration of the dynamic behaviors within Startups, and the identification of dominating loops and relevant delays, which can only be theorized through the causal models.
- **Other startup clusters should be analyzed.** Although the original focus of this work was the Robotics cluster present in Massachusetts, other relevant clusters such as the Pharmaceutical, electronic or consulting clusters can add to a deeper understanding into the dynamics of newly formed enterprises.

10 Bibliography

Ács, Z. J., Autio, E., & Szerb, L. (2014). National Systems of Entrepreneurship: Measurement issues and policy implications. *Research Policy*, *43*(3), 476–494. doi:10.1016/j.respol.2013.08.016

Barnett, C. (2013). Top 10 Crowdfunding Sites For Fundraising. *forbes.com*. Retrieved April 04, 2014, from http://www.forbes.com/sites/chancebarnett/2013/05/08/top-10-crowdfunding-sites-for-fundraising/

Beamon, B. M. (1999). Measuring supply chain performance. *International Journal of Operations & Production Management*, *19*(3), 275–292.

Berg, B. L. (2001). *Qualitative research methods for the social sciences*.

Bianchi, C., & Bivona, E. (2002). Opportunities and pitfalls related to e-commerce strategies in small-medium firms: a system dynamics approach. *System Dynamics Review*, *18*(3), 403–429. doi:10.1002/sdr.256

Blank, S. (2010). What's A Startup? First Principles. Retrieved April 14, 1BC, from http://steveblank.com/2010/01/25/whats-a-startup-first-principles/

Brinckmann, J., & Hoegl, M. (2011). Effects of Initial Teamwork Capability and initial relational capability on the development of new technology-based firms. *Strategic Entrepreneurship Journal*, *57*(5), 37–57. doi:10.1002/sej

Buckley, R. (2013). *Operations for Engineers - Literary Review* (p. 58).

Cavalcanti, G. (2013). Is it a Hackerspace, Makerspace, TechShop, or FabLab? *Makezine.com*. Retrieved April 10, 2014, from http://makezine.com/2013/05/22/the-difference-between-hackerspaces-makerspaces-techshops-and-fablabs/

Comstock, B. (2014). Welcome to the Era of the Hardware Startup. *Linkedin.com*. Retrieved April 16, 2014, from https://www.linkedin.com/today/post/article/20140205150428-19748378-welcome-to-the-era-of-the-hardware-startup

Cousins, P. D., Lawson, B., Petersen, K. J., & Handfield, R. B. (2011). Breakthrough Scanning, Supplier Knowledge Exchange, and New Product Development Performance. *Journal of Product Innovation Management*, *28*(6), 930–942. doi:10.1111/j.1540-5885.2011.00854.x

D'Andrea, R., Wurman, P. R., Barbehenn, M. T., Hoffman, A. E., & Mountz, M. C. (2011a). Patent US 7,873,469: System and method for Managing Mobile Drive Units.

D'Andrea, R., Wurman, P. R., Barbehenn, M. T., Hoffman, A. E., & Mountz, M. C. (2011b). Patent US 7,920,962: System and Method for Coordinating Movement of Mobile Drive Units. USA.

D'Andrea, R., Wurman, P. R., Barbehenn, M. T., Hoffman, A. E., & Mountz, M. C. (2011c). Patent US 8,068,978: System and Method for Managing Mobile Drive Units. USA.

De Koster, R., Le-Duc, T., & Roodbergen, K. J. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research*, *182*(2), 481–501. doi:10.1016/j.ejor.2006.07.009

Delgado, M., Porter, M. E., & Stern, S. (2010). Clusters and entrepreneurship. *Journal of Economic Geography*, *10*(4), 495–518. doi:10.1093/jeg/lbq010

Dwyer, P. (2013). The Only Startups That Matter to Job Creation. *Bloomberg.com*. Retrieved from http://www.bloombergview.com/articles/2013-08-16/the-only-startups-that-matter-to-job-creation

Enright, M. J. (2000). *Survey on the characterization of regional clusters: Initial results* (pp. 1–21).

Estes, A. C. (2014). Meet Google's Robot Army. It's Growing. *gizmodo.com*. Retrieved March 26, 2014, from http://gizmodo.com/a-humans-guide-to-googles-many-robots-1509799897

Fine, C. H. (1998). *Clockspeed : Winning Industry Control in the Age of Temporary Advantage: Charles H. Fine*. New York, NY: Basic Books.

Fine, C. H. (2013). *Notes for course: Operations for Entrepreneurs, Nail, Scale, Sail v.5, 2013*.

Forrest, C. (2014). Google and robots: The real reasons behind the shopping spree. *techrepublic.com*. Retrieved March 26, 2014, from http://www.techrepublic.com/article/google-and-robots-the-real-reasons-behind-the-shopping-spree/

Forrester, J. W. (1986). Lessons from system dynamics modeling. In *The 1986 International Conference of the System inamics Society*.

Harrison, J. D. (2013). Who actually creates jobs: Start-ups, small businesses or big corporations? *The Washington Post*. Retrieved April 16, 2014, from http://www.washingtonpost.com/business/on-small-business/who-actually-creates-jobs-start-ups-small-businesses-or-big-corporations/2013/04/24/d373ef08-ac2b-11e2-a8b9-2a63d75b5459_story.html

Heirman, A., & Clarysse, B. (2004). How and Why do Research-Based Start-Ups Differ at Founding ? A Resource-Based Configurational Perspective. *Journal of Technology Transfer*, *29*, 247.

Helmers, C., & Rogers, M. (2011). Does patenting help high-tech start-ups? *Research Policy*, *40*(7), 1016–1027. doi:10.1016/j.respol.2011.05.003

Homer, J., & Oliva, R. (2001). Maps and models in system dynamics: a response to Coyle. *System Dynamics Review*, *17*(4), 347–355. doi:10.1002/sdr.224

Hopcroft, T. (2009). *Achieving Global Leadership: A Roadmap for Robotics in MAssachusetts*. Boston, MA.

Hopcroft, T. (2012). *The Massachusetts Robotics Revolution*. Boston.

Howe, J. (2006). The rise of Crowdsourcing. *Wired Magazine*, 1–4.

Kamagaew, A., Stenzel, J., & Nettstr, A. (2011). Concept of Cellular Transport Systems in Facility Logistics, 40–45.

Kane, T. (2010). *Kauffman Foundation Research Series: Firm Formation and Economic Growth, The Importance of Startups in Job Creation and Job Destruction*.

Khamis, A. H., Utembayev, A., Nordin, M. R., Victorero, R., & Abughannam, S. (2012). *The Massachusetts Robotics Cluster*.

Kirsner, S. (2012). Rethink Robotics launches its first product: Baxter, an inexpensive and easily-trained manufacturing bot. *Boston.com*. Retrieved from http://www.boston.com/business/technology/innoeco/2012/09/rethink_robotics_readies_to_la.html

Kittur, A., Chi, E. H., & Suh, B. (2008). Crowdsourcing User Studies with Mechanical Turk. In *CHI 2008 Proceedings* (pp. 453–456).

Kroski, E. (2013). A Librarian's Guide to Makerspaces: 16 Resources. *Open Education Database*. Retrieved April 16, 2014, from http://oedb.org/ilibrarian/a-librarians-guide-to-makerspaces/

Kucera, D. (2012). Amazon Acquires Kiva Systems in Second-Biggest Takeover. *Bloomberg.com*. Retrieved from http://www.bloomberg.com/news/2012-03-19/amazon-acquires-kiva-systems-in-second-biggest-takeover.html

Kyung-Moon, K. (2013). *The impacts of founding teams' characteristics, types of opportunities, and types of strategies on firm performance in new business ventures*. Luisiana Tech University.

Li, L., Su, Q., & Chen, X. (2011). Ensuring supply chain quality performance through applying the SCOR model. *International Journal of Production Research*, *49*(1), 33–57. doi:10.1080/00207543.2010.508934

Lindtner, S., Hertz, G., & Dourish, P. (2014). Emerging Sites of HCI Innovation: Hackerspaces, Hardware Startups & Incubators. In *Computer Human Interaction 2014.* Toronto, Canada.

Lyneis, J. M., & Ford, D. N. (2007). System dynamics applied to project management a survey assessment and directions for future research. *System Dynamics Review*, *23*, 157–189.

Manuj, I., & Sahin, F. (2011). A model of supply chain and supply chain decision-making complexity. *International Journal of Physical Distribution & Logistics Management*, *41*(5), 511–549. doi:10.1108/09600031111138844

Martinez-Moyano, I. J., & Richardson, G. P. (2013). Best practices in system dynamics modeling. *System Dynamics Review*, *29*(2), 102–123. doi:10.1002/sdr

McNamara, C. (2011). General Guidelines for Conducting Research Interviews. *Free Management Library*. Retrieved April 16, 2014, from http://managementhelp.org/businessresearch/interviews.htm

Morris, R. (2014). The Greatest Myth About the Robotics Industry. *IEEE Spectrum*. Retrieved March 26, 2014, from http://spectrum.ieee.org/automaton/robotics/industrial-robots/the-greatest-myth-about-the-robotics-industry

Nisen, M. (2013). The "Devil"s Triangle' Keeps Most Startups From Growing Into Full-Fledged Businesses. *BusinessInsider.com*. Retrieved April 24, 2014, from http://www.businessinsider.com/how-to-get-past-the-devils-triangle-that-kills-company-growth-2013-2

NPR. (2014). NPR interview to Rodney Brooks 31 January 2014. Retrieved from http://www.npr.org/2014/01/31/269447242/rodney-brooks-co-founder-of-rethink-robotics

Porter, M. E. (1998). Clusters and the New Economics of Competition. *Harvard Business Review*, *76*(6).

Randers, J. (1980). *Elements of the System Dynamcs Method.* Cambridge, MA.: Productivity Press.

Richardson, G. P., & Pugh, A. L. (1981). *Introduction to System Dynamicos with DYNAMO*. Cambridge, MA.: Porductivity Press.

Robhemed, N. (2013). What is A Startup? *forbes.com*. Retrieved April 16, 2014, from http://www.forbes.com/sites/natalierobehmed/2013/12/16/what-is-a-startup/

Roure, J. B., & Keeley, R. H. (1990). Predictors of success in new technology based ventures. *Journal of Business Venturing*, *5*(4), 201–220. doi:10.1016/0883-9026(90)90017-N

Scanlon, J. (2009). How Kiva Robots Help Zappos and Walgreens. *Bloomberg.com*.

Sterman, J. D. (1994). Learning in and about complex systems, *10*(February), 291–330.

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World with CD-ROM*. McGraw-Hill/Irwin.

Stone, B. (2012). Smarter Robots, With No Wage Demands. *BusinessWeek.com*. Retrieved from http://www.businessweek.com/articles/2012-09-18/smarter-robots-with-no-pesky-uprisings

Turner, D. W. (2010). Qualitative Interview Design : A Practical Guide for Novice Investigators. *The Qualitative Report*, *15*(3), 754–760.

U.Tennessee. (2014). Startup Business Failure Rate By Industry. Retrieved April 01, 2014, from http://www.statisticbrain.com/startup-failure-by-industry/

Vennix, J. A. (1996). *Group Model Building, facilitating team learning using system dynamics* (p. 297). New York, NY: John Wiley & Sons.

Wakabayashi, D. (2014). Venture Money Flows Into Hardware Startups. *The Wall Street Journal*. Retrieved April 16, 2014, from http://online.wsj.com/news/articles/SB10001424052702303546204579438273392338520

Wu, D. D., Kefan, X., Hua, L., Shi, Z., & Olson, D. L. (2010). Modeling technological innovation risks of an entrepreneurial team using system dynamics: An agent-based perspective. *Technological Forecasting and Social Change*, *77*(6), 857–869. doi:10.1016/j.techfore.2010.01.015

Wurman, P. R., & Andrea, R. D. (2008). Coordinating Hundreds of Cooperative , Autonomous Vehicles in Warehouses. *AI Magazine*, *29*(1), 9–20.

Wurman, P. R., D'Andrea, R., Barbehenn, M. T., Hoffman, A. E., & Mountz, M. C. (2011). Patent US 7,912,574: System and Method for Transporting Inventory Items.

Yang, A. (2014). *Smart people should build things* (First Edit.). New York, NY: Harper-Collins.

11 Appendix1 Sample Information sent to interviewed companies

Daniel Alberto Sepulveda Estay

From:	Daniel Alberto Sepulveda Estay
Sent:	Wednesday, January 15, 2014 12:46 PM
To:	David Shane
Subject:	Meeting Request: MIT Sloan research on Operations/SC Capabilities development
Attachments:	Re: MIT Sloan research on Operations/SC Capabilities development meeting request

Hi Dave,

I was referred to you by Mark Smithers, due to my interest to meet with you, as I am a graduate student at MIT Sloan (where I work with professor Charles Fine) involved in a research project regarding the development of Operational / Supply Chain skills in companies within the robotics cluster present in Massachusetts.

To give a bit more background: Prof. Fine has been developing a new course for MIT Sloan School called "Operations for Entrepreneurs." The intent is to develop theory and case studies to help entrepreneurs more effectively build their manufacturing/operations/supply chain capabilities. In the entrepreneurship literature, there are dozens/hundreds of books that offer advice on finance and/or marketing for young firms, but there is very little to help operations people. Correspondingly, in the operations literature, we have a great deal of content on managing manufacturing/operations/supply chains for established companies, but much less devoted to young entrepreneurial companies.

As a part of the project, I will be focusing on manufacturing & supply chain development in robotics firms. Since we have a rich collection of these locally, we are hoping to get a decent number to participate. What we would like is to interview a few key informants at your firm, addressing a range of topics that include:

(1) make/buy strategy and decision making,
(2) supplier selection criteria,
(3) supply chain relationship philosophy,
(4) supply chain development strategy,
(5) supplier performance criteria/metrics,
(6) internal supply chain management capability development,
(7) integration of your capabilities with your suppliers' capabilities,
(8) concurrent engineering of product, process, and supply chain,
(9) data analytics/tool applied to supply chain management,
(10) lessons from your successes and failures, and
(11) others suggested by the interviewees.

Our hope is to develop some interesting/instructive case students as well as broader insights for the sector and high-tech manufacturing startups more generally. We recognize that some of the information that we seek may be considered proprietary to your firm, so we are willing to sign an NDA and limit publication to information pre-approved by you. Of course, for instructional purposes, detailed cases are especially appreciated by students, but we will subordinate that objective to achieving the right outcome for our informants, and hope we can convince you to be somewhat generous in sharing your insights and practices.

Benefits to participating firms will include access to the collective (nonproprietary) insights from the project as well as informal advice/conversations with our research team.

1

I stay alert then to your availability to meet, as of January 13th, 2014, as well as any additional information/questions you may have on this.

Best regards,

--
Daniel Sepulveda E.
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