

# Emerging Research Institutions' Technology Transfer Supply Chain Networks' Sustainability: Budget Resource Planning Tool Development

—CLOVIA HAMILTON  
MEMBER, IEEE

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**Abstract**—Emerging Research Institutions (ERIs) can benefit from patent licensing revenues from the transfer of patented technologies into the commercial marketplace because these added revenues can help research institutions become more sustainable financially. However, many ERIs struggle to succeed in technology transfer. This study describes the development of a university technology transfer supply chain network sustainability tool that private and public ERIs can use to become more self-reliant financially. Historically black colleges and universities (HBCUs) are ERIs and are used as a case study. HBCUs lag behind their peer non-HBCUs because historically they have been under-served and were originally established largely as teaching and blue-collar trade schools. Some doctoral HBCUs desire to strengthen their research activities. Systems dynamics is the process of combining the theory, method, and philosophy necessary to analyze the behavior of a system in order to provide a common foundation that can be applied whenever it is desired to understand and influence how things change over time. Applying the systems dynamics approach, a budget resource planning tool was developed using a linear programming optimization technique. This study illustrates that classic industrial uses of linear programming optimization techniques can uniquely be used to optimize budget resource planning for sustainable HBCU supply chain networks and other emerging research institutions. This study contributes to the improved execution of technology transfer projects through better budget resource planning.

**M**ANAGERIAL relevance statement—Technology transfer is a subset of technology management. The purpose of planning budget resources in tech transfer is to provide financial information, analysis, and planning support to assist with managerial decision making in alignment with the research organization's tech transfer mission and goals. The benefit to a tech the economic development in their regions. However, not all American universities have excelled in the management of their

technology transfer projects. As one may imagine, the well-established research institutions perform better than the emerging research institutions as evidenced by the Association of University Technology Transfer Managers (AUTM) annual licensing survey data.

The Federal Demonstration Program (FDP) of the National Academies is a program convened by the Government-University-Industry Research Roundtable (GUIRR) which is an organization housed in the

Policy and Global Affairs Division of the National Research Council [4]. As defined by the FDP, Emerging Research Institutions (ERIs) are institutions that are relatively new to managing federal funds whose federal research obligations for engineering and science to institutions of higher education are less than \$20 million annually in federal R&D funding as listed in the National Science Foundation (NSF)'s National Center for Science and Engineering Statistics website (formerly, the Science Resources Statistics (SRS) website). In addition, ERIs are at least funded by two (2) federal FDP federal agencies [5]. For the purpose of this research, a non-HBCU is defined as any accredited university that is not a HBCU or any other Title III institute of higher learning. As of the year 2014, nearly all of America's Historically Black Colleges and Universities (HBCUs) are ERIs; and only 0.87% of the non-HBCUs are ERIs.

Between 1994-1996, the US Air Force funded a study about how the air force could best provide technical assistance to Minority Servicing Institutions (MSIs) and HBCUs [6]. The study included 15 MSIs and 25 HBCUs. Thirty-four (34) had Offices of sponsored research. The barriers that the study participants listed included:

1. having limited resources;
2. heavy teaching loads;
3. small or no sponsored research program offices;
4. ineffective research infrastructure (lab facilities and equipment);
5. inefficient know-how on research funding opportunities; and
6. inefficient know-how about their faculty's matching fund capabilities, and ineffective grant proposal writing skills [6].

The US Air Force study included a workshop. At the 1996 workshop, the participated debated whether or not

HBCUs and MSIs should just focus on teaching and not engage in research at all [6]. The resulting sentiment was that such a debate would not help their situation and progress.

Thirteen (13) years later, the same challenges were expressed by a new group of HBCU study participants as part of an ERI study which was very similar to the 1996 US Air Force study [7]. As evidenced by the AUTM annual licensing survey, these ERIs have not made any progress in technology commercialization. In addition, whether the HBCUs have sponsored research infrastructure has been studied. However, the use of better resource planning for technology transfer project activities has not been studied.

The lack of progress being made by these ERIs is the motivation for this study. HBCUs lag behind their peer non-HBCUs because historically they have been under-served and were originally established largely as teaching and blue collar trade schools [8],[ 9]. Any tool which can be developed to help these ERIs better manage and optimize the use of their limited resources could be used to help any ERI and other public and private institutions which are emerging in research outside of the higher education arena more generally.

It is well established that supply chain management (SCM) focuses on value producing activities and processes. This is what these ERIs desperately need. Thus, this empirical study seeks to view university technology transfer in a novel way as a supply chain network for which the theory of distribution management can be applied. Most of the research in SCM addresses problems from a tactical standpoint. So, a major challenge is to increase research focused on the development of models for the strategic and tactical

planning of SCM [10]. When old paradigms lose their effectiveness, one of the reasons leaders do not solve problems right away is the lack of technological tools [11]. Optimization and advanced optimization tools can be developed to address problems with university technology transfer and to level the playing field for HBCUs.

## I. THEORETICAL FRAMEWORK

Theoretical frameworks provide a structure to support explanations for why research problems exist. The problem here is that there is a lack of HBCU engagement in tech transfer. As per the social comparison theory [13], individuals satisfy their fundamental need for accurate certainty and cognitive limpidness by finding information about the accurate certainty of their opinions and the accuracy of their abilities by sizing themselves up to others [14]. HBCUs can learn technology transfer from non-HBCUs. They can compare themselves to the non-HBCUs and improve. According to Leon Festinger, the need for comparisons to similar others leads to affiliation, pressure toward uniformity in groups, and a unidirectional drive upward that leads to competition. Upward comparisons are with individuals or groups that are believed to be better, and downward comparisons are with those that are believed to be worse off [15]. If a group believes that their own abilities and efforts do not measure up, they may be motivated to make improvements.

Beginning with lessons learned from the social comparison theory, instead of studying what a top ranked well established research university such as Stanford University, Massachusetts Institute of Technology (MIT), University of California Berkeley, University of Illinois-Urbana Champaign or Georgia Institute of Technology is doing, this study will focus on what

the emerging non-HBCUs are doing with their tech transfer programs. Three (3) of the primary lessons learned from the social comparison theory follows:

1. HBCUs should be compared to non-HBCUs of similar ability and geographic location. With respect to the social comparison of ability, individuals compare themselves with others that have similar abilities [13]. This comparison allows them to lessen their uncertainty and enhance or preserve their self-esteem. These comparisons are based on others who are in close physical proximity because such individuals are likely to be similar in key ways (Greenberg & Ashkanasy, 2007; Suls & Wheeler, 2000). Thus, physical geographic location matters.
2. Competition, cooperation and conforming are social evaluation strategies related to social rules for distributing rewards; and competitive social comparison is greatest when the comparer and other person are similar in ability [16].
3. Any comparison needs to be specific with objectively measurable attributes so as to diminish biasness [17], [18].

These lessons can be used to identify non-HBCU schools for the 24 HBCU doctoral schools to compare themselves to with regard to technology commercialization.

An ideal theoretical framework for researching the phenomenon of HBCUs being woefully behind in technology commercialization should make use of theory integration and theory triangulation. Theoretical integration occurs when two or more theories are joined because the integrated theories work more effectively than any one of the premises alone in explaining the phenomenon. There are examples in cognitive psychodynamic therapy.

However, it can be difficult to integrate theories when there are differences in philosophies, ideas, constructs and presumptions [19]. Further, theory triangulation is the analysis of data from more than one perspective, hypotheses and/or theories [20]; and it is rarely used [21]. Nevertheless, using theory triangulation and integration, the Social Comparison Theory (SCT) and Theory of Distribution Management (TDM) are joined.

The TDM is a business management theory that states that since institutions are so interlaced, *system dynamics* influences the function of product R&D, promotion and sales [1]. It is a system dynamics idea applied to production distribution as noted in Forrester's 1961 book *Industrial Dynamics* [22]. System dynamics is the process of combining the theory, method and philosophy necessary to analyze the behavior of a system in order to provide a common foundation that can be

applied whenever it is desired to understand and influence how things change over time [2]. The 1958 introduction of the Theory of Distribution Management is believed to be the first instance of a reference to SCM [1]. Supply chains are "networks" of three (3) or more organizations involved in downstream and upstream linkages. The supply chain includes value producing activities and processes. The valuables are products and services delivered to consumers that enhance performance [1], [23], [24]. The traditional SCM view is to move goods or services in a tactical manner as a cost center. University tech commercialization is a supply chain network because it is comprised of three or more organizations (i.e., the research labs, Technology Transfer Office (TTO) and industry partners that patented inventions are licensed to) as shown in Fig. 1 and Table 1.

Every organization's competitive success depends on how well its

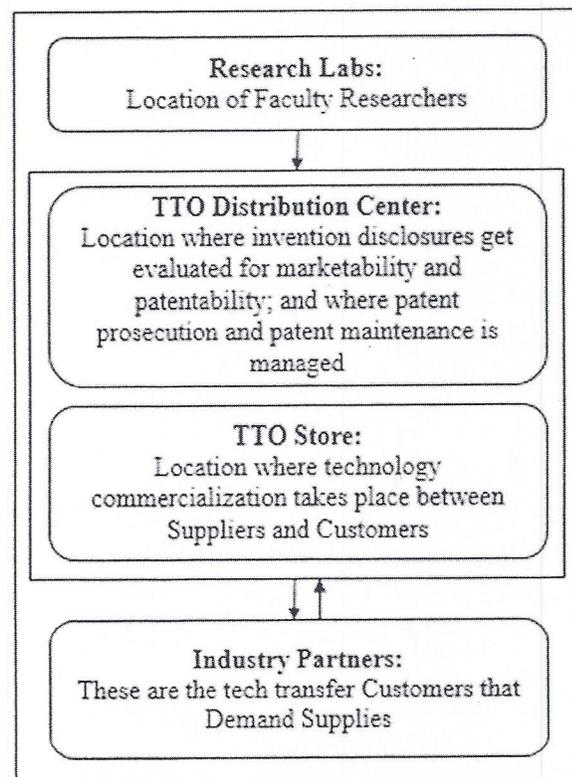


Fig. 1. Conceptual model for a university tech transfer supply chain network.

entire supply chain is able to compete by delivering value to its customers [23]. Organizations need to be adaptable because, for example, simply minimizing costs may not result in the best value [24]. Supply chains have to be managed because customers demand more value; and advanced computerized planning systems make it possible to manage supplies in order to meet demands. Advanced planning systems include optimization techniques, forecasting and scenario planning that provide what-if analyses and simulation [23]. Best value supply chains provide alignment in the interests of all participants. This alignment can be achieved through collaborative forecasting with suppliers (i.e., in university tech transfer, suppliers are the TTOs) and customers (i.e., industry licensing partners) [24]. Best value sales deals are more like teaming agreements and participants are encouraged to take the time to sit together and agree on anticipated business levels [24].

In the university tech commercialization supply chain, the supplies are patented inventions demanded by licensing partners. In this novel view the technology

transfer process as a supply chain, as listed in Table 2, a network node is a TTO distribution center (TDC), lab, or TTO store. The supply chain can begin with one or more labs and end with one or more TTO stores. The TDC's satisfy TTO stores' and demands from the marketplace.

Very little has been written about tech transfer as a supply chain network. However, product development has been recognized as a fundamental link in the technology supply chain [25]. Further, it has been proposed that product tech transfer effectiveness is greatest when companies delicately match the technology types that they want to transfer with their industrial supplier relationships in inter-organizational interactions [25].

If tech transfer is viewed from this supply chain lens, the demand for invention disclosure evaluations related to supply chain processes such as the demand forecast methods and demand arrival processes that are dedicated internal resources. In this context, university tech managers are supply chain managers aiming for efficiency to maximize licensing revenues. TTOs are impacted by inventory reduction

and fill rates, customers' satisfaction, revenue loss; and the costs for inventory, managing resources are the most significant tasks of a capable supply chain manager. Further, in traditional supply chains, in order to protect against defects, unstable production, supply and demand imbalances, and uncertainties, inventory is held [26]. This tight inventory control is not the goal in university technology transfer. But, minimizing the time to evaluate invention disclosures, minimizing costs, and maximizing licensing revenues are issues for TTOs. In addition, university tech transfer is a process oriented professional industry. Interestingly, there is a need for future research in SCM planning and scheduling in process industries [10], [27]. Few supply chain operation scholarly contributions deal with process industries [10], [28]. Thus, university tech transfer supply chains are complex network systems. Modelling and simulation can be used to investigate, find optimal solutions, and predict outputs in such complex networks.

Financial resource planning is a best practice in tech transfer. Patenting and marketing to potential industry licenses is very expensive. This is a real problem and balancing act for TTO directors [29]. With each invention disclosure, TTOs must decide whether to invest funds, patent and market the technology quickly or they miss opportunities. A study of TTO directors revealed that 20.3% of the TTOs have to be self-sufficient and fund at least 50% of their operating budgets [30]. Thus, budget resource planning is crucial for all research universities and this is even more crucial an issue for budget strapped HBCUs. The level of resources committed to university tech transfer programs is the greatest determinant of success [31].

The development of the proposed Budget Resource Planning Tool is

**Table 1. University Tech Transfer Supply Chain Network**

Traditional supply chain network	University tech transfer supply chain network
Suppliers	Tech transfer specialists that evaluate inventions
Manufacturers Plants	Faculty inventors Research labs
Distribution Centers (DCs) Stores	Tech transfer offices (TTOs) TTO Distribution Centers (TDCs)
Inventory	Invention disclosures Patent applications Patents
Inventory costs	Legal fees
Customers	Faculty inventors Industry partners

**Table 2. Typical Supply Chain vs. University Tech Transfer Supply Chain**

Typical supply chain	Tech transfer supply chain
Store	TTO store
Distribution Center	TTO distribution center
Plant	Research Labs
Customers	Industry Partners

important because the literature review revealed that the TTOs need clear goals, priorities, resource planning, and planned investments of their financial resources [32]–[34]. This is even more imperative for emerging research institutions such as the HBCUs which have more limited resources. Further, TTOs need to be adequately resourced with, for example, adequate:

- legal budget,
- TTO staff compensation,
- in-house venture capital program (esp. for medical related inventions), and
- business incubator [33], [35]–[37].

It costs money to make money. Investments have to be made in providing and managing the necessary resources to operate a technology commercialization program successfully. The proposed Budget Resource Planning Tool is designed with the theoretical framework for research in mind. In particular, it was designed from the viewpoint that university technology transfer is a supply chain network. Five (5) steps were taken to develop the Budget Resource Planning Tool are described and include the:

1. development of the concept model for the university technology transfer supply chain network;
2. development of a licensing revenue optimization model;
3. collection of cost and supply capacity data;
4. experimentation; and
5. model validation.

## II. METHOD

### A. University Tech Transfer Supply Chain Network Concept Model

The first step is the development of the concept model for university technology transfer supply chain network. A concept model for a novel university technology supply chain network. Table 2 provides an analogy between the elements of a

typical, traditional supply chain and the proposed tech transfer supply chain network; and as aforementioned, Fig. 1 shows a proposed university technology transfer supply chain network.

A Supply Chain Network (SCN) is a master operational network involving geographically dispersed resources [10]. In the university tech transfer process, these resources come from geographically dispersed research centers on and off campus. This SCN also involves geographically dispersed market places. In university tech transfer, the geographically dispersed markets are represented by geographically dispersed industry partners.

The research labs' faculty inventors submit completed invention disclosure forms to the TTO distribution center. Once inventions are ready for tech commercialization, the TTO distribution center submits the invention to the TTO store as shown in the conceptual model for the university technology transfer supply chain network in Fig. 1. the focus on environmental management and operations has moved from local optimization of environmental factors to consideration of the entire supply chain [38] In case studies, it is useful to examine the supply chain in its entirety [39]. Thus, the entire university technology transfer supply chain is considered herein.

The TTO store and distribution centers are **Suppliers**. The literature review revealed that 72% of the TTOs have three (3) or fewer full time equivalent (FTE) staff members [40]. The larger well regarded TTOs have staffs of 4 to 6.5 FTEs per \$100 million of extramural research awards [31]. In the university technology transfer supply chain network, each TTO staff person can be a supplier that seeks to meet customer demands. The TTO staff may pitch patented inventions and travel to the potential industry partners; or these potential customers may come to the TTO store. Thus, their interchange is shown in Fig. 2 as bidirectional. This is a dense network because each supplier can work to supply each industry partner customer's **Demands**.

$S_i$ , Suppliers are TTO staff persons  
 $D_j$ , Industry partner customer demands  
 $C_j$ , TTO invention capacity  
 $C_{ij}$ , Cost that Suppliers  $i$  incur when interacting with customers  $j$   
 $x_{ij}$ , Licensing deals

Common university tech transfer costs include the legal costs of patenting; and the TTO staff labor costs. The TTO staff persons are typically the individuals who work to negotiate licensing deals between their university and the industry partners that are seeking to license university technology. Fig. 1 illustrates this university tech transfer supply chain network.

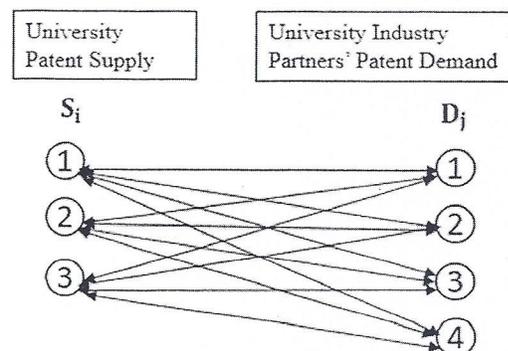


Fig. 2. Conceptual model for university technology transfer supply chain network.

**B. Development of a Licensing Revenue Optimization**

**Model** The second step is the use of the classic supply chain warehouse shipment transportation model, a simple linear programming model was developed to maximize the licensing revenues between suppliers *i* and customers *j* in order for TTOs to recuperate licensing costs. The costs include TTO labor and patenting legal fees.

**C. The Classic Warehouse Shipment Transportation**

**Model** Before explaining the method used to develop a linear programming optimization tool to maximize university technology licensing revenues between the Suppliers *i* to the Customers *j* (i.e., Industry Partners) with Demands *D<sub>j</sub>*, an explanation of the classic warehouse shipment transportation model is necessary. The classic supply chain warehouse shipment transportation model can be solved with Excel Solver as illustrated in Table 3.

Here are the variables in the Classic Transportation problem [41]:

- F<sub>i</sub>* – Fixed Costs
- S<sub>i</sub>* – Supply
- D<sub>j</sub>* – Demand from each customer
- X<sub>ij</sub>* – the amount shipped from *i* to *j* (i.e., from supplier *i* to customer *j*)
- M* = a large value = *S<sub>i</sub>*
- C<sub>ij</sub>* = unit transportation cost from *i* to *j*

The objective function is to minimize the transportation costs:

$$\text{Min } \sum_i \sum_j C_{ij} X_{ij} + \sum_i F_i Y_i \quad (1)$$

subject to (s.t.) the following constraints:

$$\sum_i X_{ij} \geq D_j \quad (2)$$

(i.e., amounts to be shipped from *i* to *j* need to be greater than the demand)

$$\sum_j X_{ij} \leq S_i \quad (3)$$

(i.e., amounts to be shipped from *i* to *j* need to be less than or equal to supplies)

$$\sum_j X_{ij} - M Y_i \leq 0 \quad (4)$$

(i.e., if this is positive, this logical constraint, the *M Y<sub>i</sub>* must be positive and *Y<sub>i</sub>* must be equal to one)

$$X_{ij} \geq 0 \quad (5)$$

$$Y_i \in (0, 1) \quad (6)$$

1 if the warehouse is opened and 0 otherwise.

Rows 1, 2 and 3 in Table 3 contains transportation cost data for shipping supplies from Warehouses (i) 1, 2 and 3 to their destinations. The destinations are the Customers (j) A, B, C and D denoted by the columns in Table 3. The upper matrix simply supplies the cost information. For example, cell A1 = \$0.6 to ship supplies from Warehouse 1 to Customer A.

The Supply column in the upper matrix provides the supply from each of the Warehouses. So, for example, Warehouse 1 can supply 10,000 units. The Demand row in the upper matrix provides each of the Customer's supply demands. For example, Customer A wants 8,000 units.

This linear programming model is a decision support optimization tool commonly used in supply chain management. The decisions to be made are located in the lower matrix denoted by rows 5, 6 and 7 for the three Warehouses and columns A, B, C, and D for the four Customers. The decision to be made is how much supply to ship from each Warehouse to each Customer. This problem is solved using Excel Solver and provides an optimal solution based on a Simplex linear programming algorithm.

In Excel Solver, the total cost of shipments to all of the Customers from all of the Warehouses is minimized by changing the values of the cells in the lower matrix of Table 3. The Customer demands satisfied are computed and entered into Row 9. The row totals for the Warehouses rows 5, 6 and 7 are also computed and represent the amount shipped out of each Warehouse and received by the Customers.

Next, the constraints are specified in Excel Solver. The goal is to make sure that the amount received by the Customers is equal to or more than

*Table 3. Classic Warehouse Shipment Transportation Network Design Problem in Supply Chain Management*

	COSTS	CUSTOMER A	CUSTOMER B	CUSTOMER C	CUSTOMER D	SUPPLY from each warehouse
①	WAREHOUSE 1	0.6	0.56	0.22	0.4	10000
②	WAREHOUSE 2	0.36	0.3	0.28	0.58	15000
③	WAREHOUSE 3	0.65	0.68	0.55	0.42	15000
④	DEMAND	8000	10000	12000	9000	
	SHIPMENTS	CUSTOMER A	CUSTOMER B	CUSTOMER C	CUSTOMER D	Row totals
⑤	WAREHOUSE 1	0	0	10000	0	10000
⑥	WAREHOUSE 2	5000	10000	0	0	15000
⑦	WAREHOUSE 3	3000	0	2000	9000	14000
⑧	Column Totals	8000	10000	12000	9000	
⑨	Total cost	\$13,830				Source: [41]

what is actually demanded. Recall that the Customer demand totals are in Table 3, Row 4. The total shipment amounts must be less than or equal to the amount of supply that is available. Lastly, unconstrained variables are made non-negative because a negative amount cannot be shipped. The Excel Solver solution is provided in Table 3. See cells A, B, C and D and rows 5, 6 and 7. The total minimized cost is provided in row 9. Next, an explanation of how this can be used in technology licensing is provided.

#### D. Using the Classic Warehouse Shipment Transportation Model in Tech Licensing

The next step is to make use of the Classic Warehouse Shipment Transportation Model in the tech licensing arena. Using the aforementioned classic supply chain warehouse transportation problem example, a similar linear programming optimization tool was developed with the purpose of maximizing patent licensing revenues in order to recuperate patenting and TTO staff labor costs. The patent licensing of university technology is between the Suppliers  $i$  (i.e., TTO staff licensing specialists) to the Customers  $j$  (i.e., Industry Partners) as follows:

$S_i$ , Supplies are patented invention licensing deals

$D_j$ , Customer demands

$C_{ij}$ , Cost that Suppliers  $i$  incur when licensing the patented inventions to customers  $j$

$x_{ij}$ , Amount of patented invention licensing deals to be licensed between Supplier  $i$  and Customers  $j$

$$\text{Max } \sum_i \sum_j C_{ij} X_{ij} \quad (7)$$

s.t. the following constraints:

$$\sum_i X_{ij} \geq D_j \quad (8)$$

(i.e., amounts of patented inventions to be licensed from  $i$  to  $j$  need to be greater than the demand)

$$\sum_j X_{ij} \leq S_i \quad (9)$$

(i.e., amounts of patented inventions to be licensed from  $i$  to  $j$  need to be less than or equal to supplies)

$$X_{ij} \geq 0 \quad (10)$$

In addition, each supplier (i.e., licensing specialist) would realistically not close more than five (5) deals per year; and should close at least five (5). If there is at least one prospective customer per month out of the year (12 total), each would not likely license more than two (2) patents but would likely be interested in at least one (1). This type of supply chain may be considered a service supply chain rather than a product supply chain. The next step in developing the budget resource planning tool is cost and supply capacity data collection.

The third step was the collection of cost and supply capacity data. The social comparison theory teaches that entities are most likely to emulate other entities that are in the same geographic location and that are of similar ability [13]. Applying the social comparison theory, nine (9) non-HBCU schools were identified and selected that HBCUs can emulate. Here, ability is based on licensing revenue generation. The selected non-HBCUs are non-HBCUs in the lowest quartile of licensing revenues reported in the AUTM annual licensing survey.

Using the list of non-HBCUs selected in the development of the benchmarking tool, data was collected from the years 2010-2014 about legal expenditures, staff sizes, and total licensing deals from the AUTM database. In addition, salary information was collected from the US Department of Labor's Bureau of Labor Statistics database; and the number of patents was collected from the USPTO patents database.

The cost and supply data is comprised of the mean values for the non-HBCUs' legal fees, estimated labor expenses, and total number of patented inventions in inventory. The legal fees and labor expenses were summed to provide a total expense. This cost information provides evidence of what a licensing deal between a supplier and customer will likely cost.

The fourth step is experimentation. The cost and supply data for the select non-HBCUs was inputted into the budget resource planning tool linear programming model for experimentation. The mean total expense was divided among the three (3) hypothetical TTO staff persons who serve as suppliers; and among their 12 hypothetical customers who are the potential licensees. This value was entered as cost data the Microsoft Excel Solver linear programming optimization tool.

The mean value of the total patented inventions owned by the non-HBCUs was also divided between the three (3) TTO staff suppliers. This value was used as patent inventory. The benchmark for the number of licensing deals (determined once the benchmarking tool was developed) was used for the total demand from customers.

The customer demands are defined by the number of patented inventions customers are willing to license per year. Each customer would typically license one patented invention. Alternatively, the customer demands can be defined in terms of the amount of money they are willing to invest in a licensing deal. Microsoft Excel Solver was used to compute the optimum number of licensing deals given the objective of maximizing the TTO supplier revenue in an effort to recuperate patenting and TTO labor costs.

The last, fifth step is model validation. There are several approaches to

model validation [42]. In statistics, the standard method to estimate uncertainty is to perform the experiment multiple times and independently. "The scatter in the differences between model prediction and the experimental observation can be used to make estimates about the statistics of the uncertainty" (Hills, 1999). However, it can take a lot of time to run multiple experiments. Therefore, prediction uncertainty can be estimated through analysis. For example, one can calculate probability density functions estimates for model parameters with uncertainty that appreciably impacts the model predictions. A *propagation of uncertainty analysis* can be used to estimate model prediction uncertainty. Then, with testing, a decision can be made about whether the model predictions are statistically consistent with the observations in the experiment.

*A simple graphical comparison* between the simulated measurements and the model predictions using the mean values of the model parameters can be conducted [42]. If significant differences in the trend of the model predictions relative to the experimental results are visual, then there would not be much confidence that the model is valid.

In this study, model validation was achieved with a *scenario analysis* to depict the proposed model's feasibility. With scenario analyses, an example project is used to assess the model's capability and to validate the proposed model [43]. Further, in the linear programming optimal solution may be unbounded or infeasible; multiple solutions may be found; or there might be degeneracy. The following steps are criteria that can be used to validate the model [44]:

- If unbounded, to resolve there must be a check on the

formulation of the constraints to see if one or more constraints are missing or mis-specified.

- If there are multiple optimal solutions, to resolve, the coefficients in the objective function and the constraint need to be checked. Also, there could have been rounding errors.
- If there is no solution, the model may need to be reformulated after checking the constraints' formulations to see if there are missing or mis-specified constraints.
- In addition, the sensitivity ranges for linear programming problems may be computed.

An experiment was conducted involving use of the Microsoft Excel Solver Simplex LP optimization tool to compute the optimal number of inventions to licenses to each customer with the objective to maximize licensing revenues. The results of the experimentation are presented next.

### III. RESULTS

One (1) experiment was conducted. First, three (3) lessons from SCT research were applied:

1. HBCUs should be compared to non-HBCUs of similar ability and geographic location. With respect to the social comparison of ability, individuals compare themselves with others that have similar abilities [13]. This comparison allows them to lessen their uncertainty and enhance or preserve their self-esteem. These comparisons are based on others who are in close physical proximity because such individuals are likely to be similar in key ways (Greenberg & Ashkanasy, 2007; Suls & Wheeler, 2000). Thus, physical geographic location matters.
2. Competition, cooperation and conforming are social evaluation strategies related to

social rules for distributing rewards; and competitive social comparison is greatest when the comparer and other person are similar in ability [16].

3. Any comparison needs to be specific with objectively measurable attributes so as to diminish biasness [17], [18]. Thus, the variables used for comparison had to be measurable and objective.

A sample of 24 accredited HBCUs offering Carnegie classified Research Doctoral degree programs was drawn from the list of HBCUs reported by the White House Initiative on HBCUs. The US Department of Education's National Center for Education Statistics (NCES) search tool for schools and colleges was used to identify non-HBCU schools for the HBCUs to compare themselves to. NCES provides student enrollment and geographic location [45]. The non-HBCU selection criteria was to find schools of similar ability based on student enrollment and therefore the school's ability to attract and enroll a certain number of students. Similar ability was also based on having lower licensing revenues. The second criterion was that the selected non-HBCUs had to be in the same geographic location. Thus, the non-HBCUs were selected from the same 17 states that the 24 HBCUs were located in. Third, there had to be available data for measurable and objective technology transfer data such as that provided by the AUTM annual licensing survey.

From these SCT lessons and criteria, the following nine (9) non-HBCUs were chosen for the HBCUs to compare themselves to:

- Baylor University
- Georgia Regents Health Sciences
- Medical University of South Carolina
- Wake Forest University



the potential licensees. Thus, the value  $\$1,154,163/36 = \$32,060$  was entered as cost data in each of the upper matrix cells of Table 4 for the Microsoft Excel Solver linear programming optimization exercise.

The mean value of 65 total patented inventions was also divided between the three (3) TTO staff suppliers. Typically, in a TTO, the three (3) licensing specialists will be responsible for managing a patent portfolio of a subject matter within the specialist's expertise. So, in this experiment, Supplier 1 manages 15 biotech patents, Supplier 2 manages 10 software patents, and Supplier 3 manages 40 pharmaceutical patents. In this exercise, the demand was set at 12. The goal is for each Supplier to close one deal each month. The values shown in the lower matrix of Table 4 are the results of the Microsoft Excel Solver optimized solution for maximizing the patent licensing revenues while meeting customer demands and other constraints. The goal is to recuperate the TTO's labor and patenting legal costs.

Rows 1, 2 and 3 in Table 4 above contains licensing cost data for licensing from the TTO licensing specialists herein called Suppliers (i) 1, 2 and 3 to the Customer destinations. The destinations are the Customers (j) denoted by the columns A to L in Table 4.

The upper matrix simply supplies the cost information. For example, cell A1 = \$32,060 to license supplies of patented inventions from Supplier 1 to Customer A.

The Supply column in the upper matrix provides the supply in terms of amount of patented inventions that each Supplier is responsible for licensing. So, for example, Supplier 1 can potentially supply 15 patented inventions to Customers. The Demand row in the upper matrix provides each of the Customer's

supply demands. For example, Customer A wants to license one (1) patented invention.

The decisions to be made are located in the lower matrix denoted by rows 5, 6 and 7 for the three (3) TTO Suppliers and columns A through L for the 12 Customers. The decision to be made is how much supply of patented inventions to license from each Supplier to each Customer. This problem is solved using Excel Solver and provides an optimal solution based on a Simplex linear programming algorithm.

In Excel Solver, the total licensing revenues from all of the Customers from all of the Suppliers is maximized by changing the values of the cells in the lower matrix of Table 4. The Customer demands for patented inventions satisfied are computed and entered into Row 9. The row totals for the Suppliers rows 5, 6 and 7 are also computed and represent the amount licensed out of each Suppliers' supply of patented inventions and received by the Customers.

Next, the constraints are specified in Excel Solver. The goal is to make sure that the amount received by the Customers is equal to or more than what is actually demanded. Recall that the Customer demand totals are in Table 4, Row 4. The total amounts of patents to be licensed must be less than or equal to the amount of supply of patented inventions that are available. Lastly, unconstrained variables are made non-negative because a negative amount cannot be licensed. The Excel Solver solution is provided in Table 4. See cells A, B, C and D and rows 5, 6 and 7. The total maximized licensing revenues is provided in row 9. This will enable the HBCU to plan its labor resources (i.e., the use of its TTO licensing staff suppliers) in order to recuperate their labor costs and patenting legal fees.

## V. DISCUSSION

Since the 1980 passage of the Bayh Dole Act, many American research universities have actively managed technologies created in their research labs by managing technology transfer activities [3]. These activities include the patenting, marketing and licensing of the technologies in an effort to raise licensing revenues. It is obvious that all higher education institutions can benefit from increased financial resources. ERIs are fledgling and need the additional revenues to fund their growth and development. HBCUs are ERIs and are used as a study case of ERIs for this research. HBCUs' research and development was studied by the US Air force in 1996 and in 2009. By 2009, they showed no progress in the development of their technology commercialization programs. As of 2016, HBCUs remain woefully behind in research development and technology transfer [49] In the 1996 and 2009 studies, limited resources were identified as a challenge for HBCUs. This research is motivated by the stance that better planning of the limited resources will help these ERIs improve their technology transfer management and performance. To date, whether the HBCUs have sponsored research infrastructure has been studied. However, the use of better resource planning for technology transfer project activities has not been studied.

The first step in project budgeting is resource planning. The planned resources justify proposed technology transfer project budgets. The budget provides an explanation of how the resources will be used and allocated. The proposed budget resource planning tool estimates the required inputs and means necessary to carry out technology transfer activities. Herein, it is proposed that project resource and budget planning can help technology transfer managers improve their technology

transfer performance. This research reveals that the proposed budget resource planning tool using linear programming optimization can serve as a means for ERIs to determine technology transfer project budgets. The practical implication of this research is that it can help ERI technology transfer managers determine the optimal required resources and costs so that technology transfer project budgets can be set. Resources included in the experimentation were limited to patenting and licensing costs, staff labor expenses. The resources did not include the cost of physical resources such as office facilities, or travel expenses.

The proposed budget resource planning tool is unique and original for three (3) primary reasons:

- (1) It uniquely recognizes university technology transfer (aka technology commercialization) as being part of a supply chain network of three or more organizations (i.e., research lab, technology transfer distribution center, technology transfer store and industry partners/customers);
- (2) It uses a novel theoretical framework which includes lessons learned from the Social Comparison Theory research and use of the Theory of Distribution Management; and
- (3) It uses the Classic Warehouse Shipment Transportation Model of optimizing supplies to meet customer demands.

From this novel perspective, HBCU technology transfer managers can socially compare themselves to peer non-HBCUs and in doing so, be motivated to improve their performance. From the lens that technology transfer is a part of a supply chain network for which system dynamics influences product research, development, promotion and sales, the process of system dynamics is applied. System dynamics is the process of combining theory, methods and philosophy to analyze system behavior and how things can change over time. As mentioned in the Introduction, advanced supply chain planning can address a number of decisions about the coordination, design and short term scheduling of supply chain processes [12].

## VI. CONCLUSION

The traditional supply chain network from product manufacturing to customer sales and support is not the same as for the proposed university technology transfer supply chain network and its required distribution management. The primary difference is that in the traditional supply chain network, there is typically mass production and mass sales volumes in a steady stream of supply and demand that needs to be managed. However, on the contrary, in the university technology transfer supply chain, there are occasional transfers of patent products [25].

Having a financial resource planning system is a best practice in tech

transfer. With regard to the novel view of university tech transfer as a supply chain network, budget resource planning using the proposed linear programming optimization tool is a viable way toward sustainability of university technology transfer supply chain networks. Use of budget resource planning can be tested with future research to measure the development and sustainability of HBCU tech transfer supply chain networks. Patenting and marketing to potential industry licenses is very expensive. This is a real problem and balancing act for TTO directors [29]. With each invention disclosure, TTOs must decide whether to invest funds, patent and market the technology quickly or they miss opportunities. A study of TTO directors revealed that 20.3% of the TTOs have to be self-sufficient and fund at least 50% of their operating budgets [30]. Thus, budget resource planning is crucial for all research universities and this is even more crucial an issue for budget strapped emerging research institutions such as HBCUs. The level of resources committed to university tech transfer programs is the greatest determinant of success [31]. This study illustrates that classic industrial uses of linear programming optimization techniques can uniquely be used to optimize budget resource planning for sustainable HBCU supply chain networks. It is also applicable to other emerging research institutions.

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**Clovia Hamilton** (M'17) was born in Chicago, IL, USA, in 1966. She received the MBA degree from Wesleyan College, Macon, GA, USA, JD from Atlanta's John Marshall Law School, Atlanta, GA, USA, the Master of Laws degree in intellectual property law from the University of Illinois at Urbana Champaign, Champaign, IL, USA, and the Ph.D. degree in industrial & systems engineering from the University of Tennessee, Knoxville, TN, USA, in 1996.

Since 1996, she has been a licensed attorney and since 2000, she has been a registered patent attorney with the University and Federal Lab Technology Innovation and Commercialization Experience. She worked as the Director of Intellectual Property and Research Compliance, Old Dominion University and as a Technology Transfer Specialist for the EPA's National Vehicle and Fuel Emissions Lab and the University of Illinois Urbana Champaign. From 2005 to 2015, she taught business law and ethics as an Adjunct Professor and Lecturer. Her research interests include business law and ethics, technology management, academic entrepreneurship, university–industry partnerships, university and federal lab technology transfer operations as supply chain networks, intellectual property, and scientific misconduct.

Dr. Hamilton is a member of the Institute of Industrial & Systems Engineers, INFORMS, American Society of Engineering Managers, and Academy of Management. She is the recipient of Association of American University Women Career Development Grant for 2013–2014.