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System Dynamics Investigation of Capacity Building by Humanitarian Supply Chain in Disaster Prone Eco-Communities of India

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Abstract

Humanitarian Supply Chain (HSC) is central to any developmental initiative meant for capacity building in the eco-communities of India, particularly for those which are located in disaster prone regions. Although being environmentally rich, such class of rural or tribal eco-communities and their people are often devoid of supplies of adequate Physical, Social, Economic, and Technological resources and are forced to struggle on a daily basis to survive and are unable to cope with any additional stress factors like population growth and abject poverty. In this regard, sustainable humanitarian supply chain practice and community based resource management can collectively promote more resilient communities promoting social, economic and environmental equity and ethical imperatives for sustainable community development. Apart from providing immediate relief assistance at the occurrence of natural disasters, what is more critical is their long term capacity building with a holistic perspective. This is also vital to enhance the effectiveness and speed of community response to major humanitarian programs, such as health, food, shelter, water, sanitation and employment.

In this study, an attempt has been made to develop a system dynamics model of humanitarian supply chain in order to capture causal dynamics and inter linkages within the system under investigation and suggest some critical intervention strategies for enhancing overall performance. In this study, an economic sub-sector base model for the Indian tribal communities has been calibrated and used for simulation analysis as a reference case-study. The key motivation to select tribal regions for our model was that the various humanitarian measures undertaken under India Eco-Development Project (IEP) by the Indian government are not able to meet the intended objectives.

Key Words: Humanitarian Supply Chain, Eco-Communities, Capacity Building, System Dynamics Modeling & Simulation, Scenario analysis.

Section-I

Introduction:

Eco-communities are human-scale, full-featured settlements in which human activities are harmlessly integrated into the natural world. It is potentially supportive of healthy human development, and can be successfully continued into the infinite future. Demographically, these can be urban or rural communities of people, who strive to integrate a supportive social environment with a low-impact way of life. The primary motivation for eco-communities is the choice and commitment to reverse the gradual disintegration of supportive social/cultural structures and the upsurge of destructive environmental practices on our planet. Although being environmentally rich, these people, particularly under the rural or tribal setting, are often devoid of supplies of rich Physical, Social, Economic, and Technological resources and they are forced to struggle on a daily basis to survive and are unable to cope with any additional stress factors like population growth and abject poverty. Limited livelihood alternatives, competition over scarce resources, weak educational-governance structures and lack of access to healthcare can compromise a community's ability to respond to a hazard event.

In this regard, sustainable humanitarian supply chain management and community based resource management can collectively promote more resilient communities through supporting sustainable livelihoods, conflict prevention and strengthening cooperation for good governance. Moreover, sustainable HSCM is universally considered to promote social, economic and environmental equity and ethical imperatives for sustainable community development.

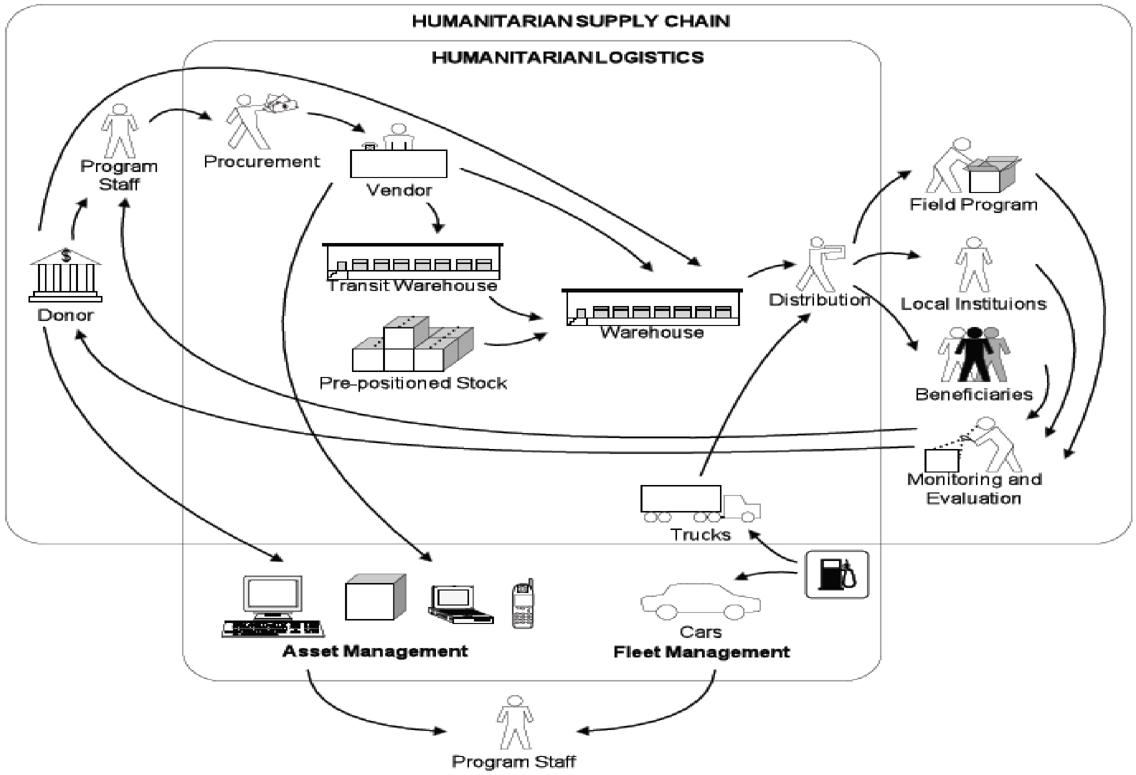


Figure 1. Humanitarian Logistics and Humanitarian Supply Chain Flows

In the present paper, special attention has been given to the development of a sustainable humanitarian supply chain model comprised of various delivery sub-systems and their causal relationship indicating key decision-points for community development.

Significance of Study:

Environmental conservation and disaster management are critical to the livelihoods of indigenous people who often live in hazard-prone areas. They have built up, through hundreds of years of experience and intimate contact with the environment, a vast body of knowledge on hazards and the environment events. This knowledge is a precious resource that continues to contribute to environmental conservation and disaster management in these regions. However, with the disruption of traditional lifestyles, changing settlement patterns and most significantly, because of the socio-economic-technological deprivation, it is a challenge to maintain the environmental capital of these communities. Hence, an active communion and delivery mechanism is primarily required among various resource-sectors like Physical, Social, Economic and Technological.

System Dynamics Modeling and Simulation:

Borrowed from the system theory, this paper offers a dynamic approach of complex system analysis and modeling in the form of System dynamics. Its utility is significant in capturing structural complexities of Humanitarian supply chain in a holistic sense. System dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems (*Sterman et al 2000)*. System dynamics (SD) methodology emphasizes on internal feedback loop process and deals with the causal relations between the dynamic behavioral analysis and multi-variables that enables to represent the structure and behavior of complex systems over time, providing a method for systems description as well as a useful computational support for simulation (Forrester 1999, Sterman, 2000, Sabine et al. 2005, Maier 1998).

The modeling and simulation process of system dynamics covers the following steps:

1. Description of Model boundary in terms of modelling needs and priorities
2. Identification of relevant input variables and parameters
3. Model building, testing and validation
4. Scenario-sensitivity analysis
5. Policy formulation and implementation

Building Generic Humanitarian Supply Chain Model for Eco-Communities:

Applying the system dynamics modeling approach, we have identified key system boundaries and input variables as depicted in the conceptual model (Figure 2) structure. In this model, humanitarian supply chain links the sources of "supply" (donor institutions or suppliers) to the owners of "demand" (end customers in the identified eco-community). Under this holistic structure, various societies and co-operatives are the primary parties involved under a central administrator agency control. Central Administrator holds main power with the control it has over the entire supply line directly affecting the flows-both Information and Physical, with their decisions. Though, this supply network is huge and complicated with numerous players, it is not that hard to coordinate them along with all the services that are needed to be delivered. Despite the varying objectives and functional differences; collaboration and specialization of the tasks between donor institutions can be improved by clearly defining their goals, scope of activities and mutual interplay.

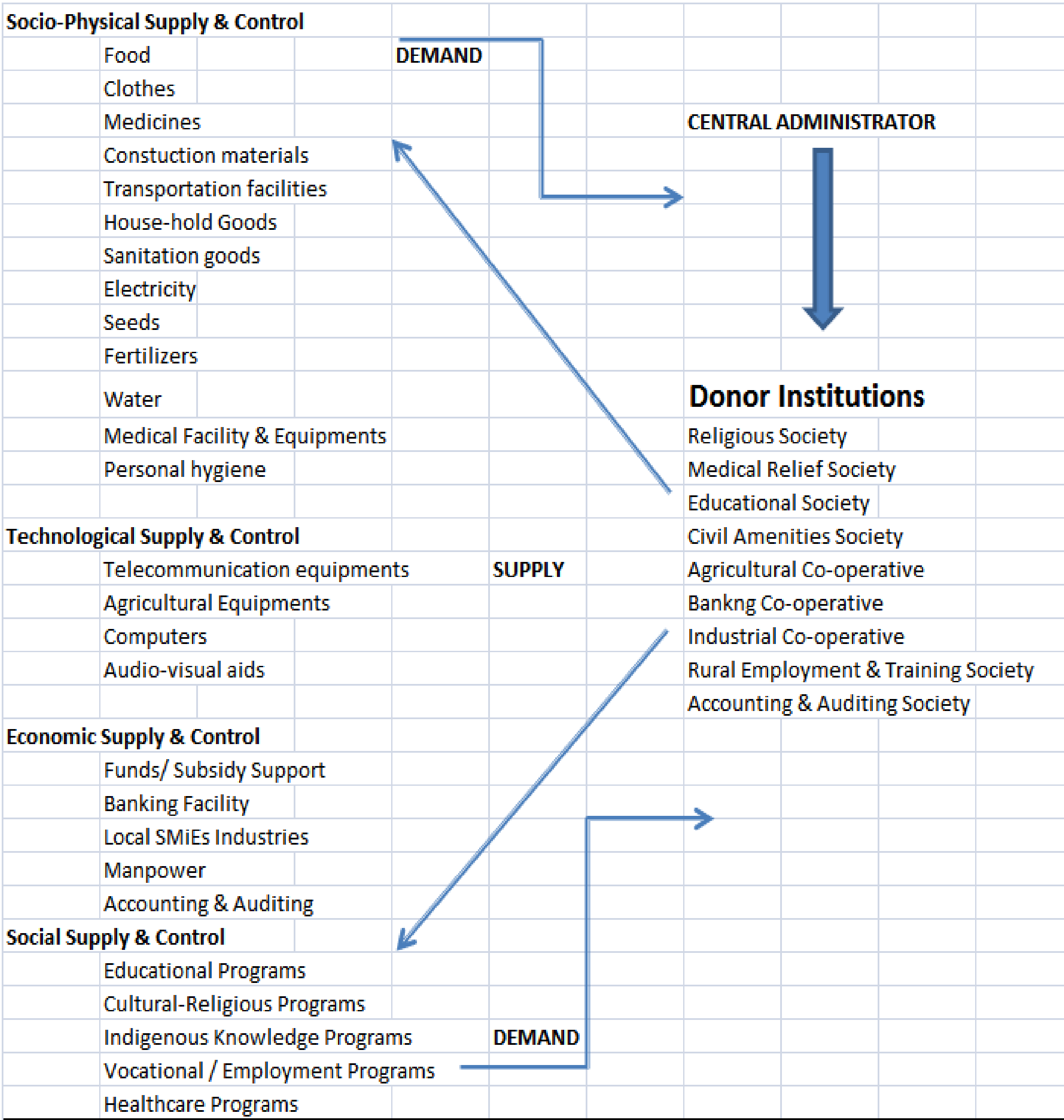
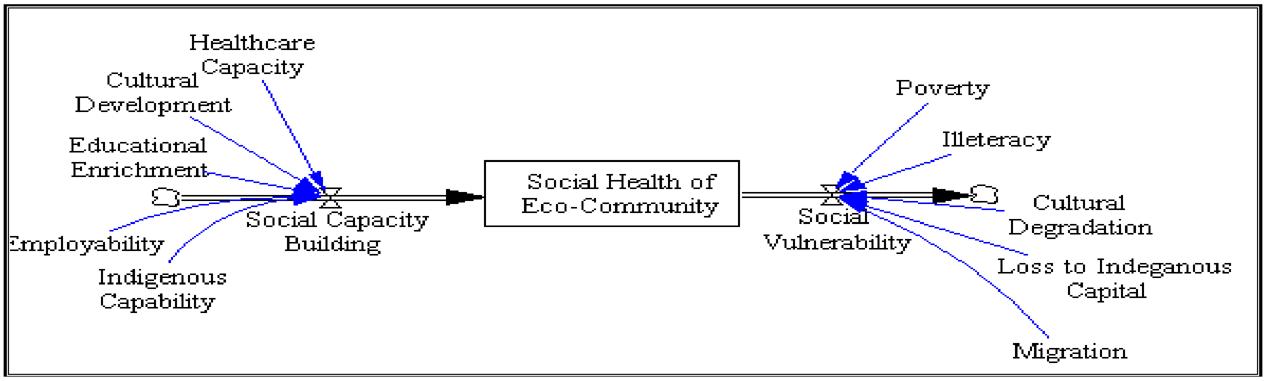


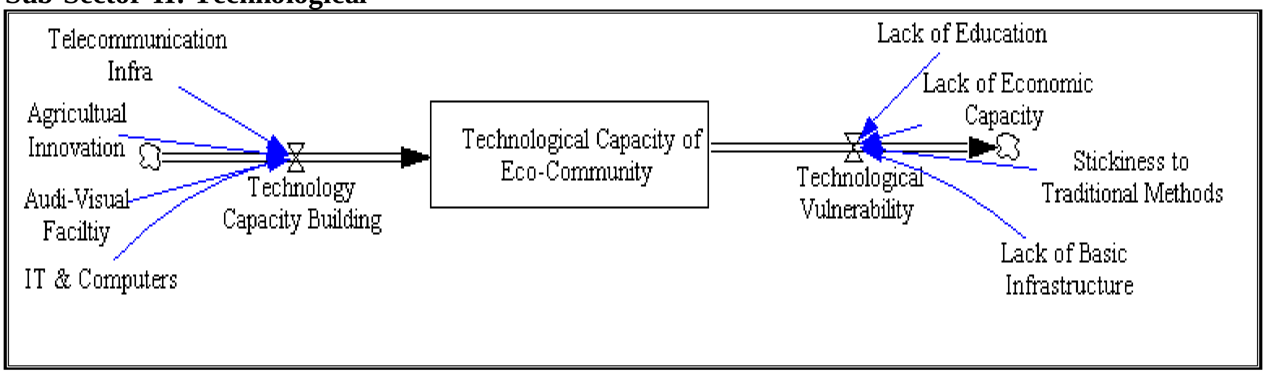
Figure 2: A Schematic Outline of Humanitarian Supply-Chain and Control Framework

Now, after defining system boundaries and input variables for modeling, we need to provide a stock-flow structure to them for the intended purpose of simulation and policy analysis. The holistic humanitarian supply chain model can further be segregated into various constituting sub-sectors with respective stock-flow variables and their influence flow as projected below in Figure 3. In addition to the supply line variables identified in the previous figure, the present model also indicates critical vulnerabilities as outflows, which might drench out the inflow-supplies benefits (considered for capacity building) and counter balance the growth of the overall system.

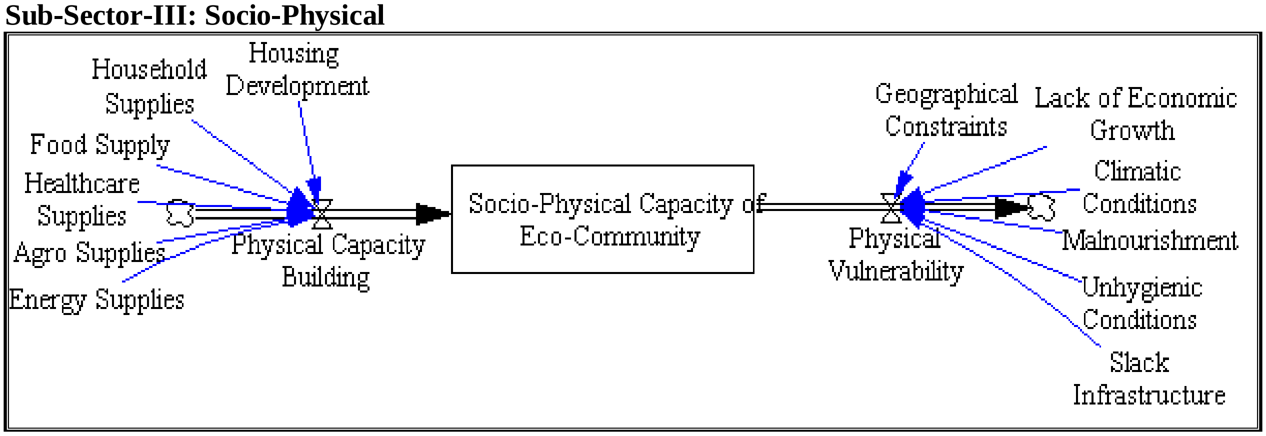
Sub-Sector-I: Social



Sub-Sector-II: Technological



Sub-Sector-III: Socio-Physical



Sub-Sector-IV: Economic

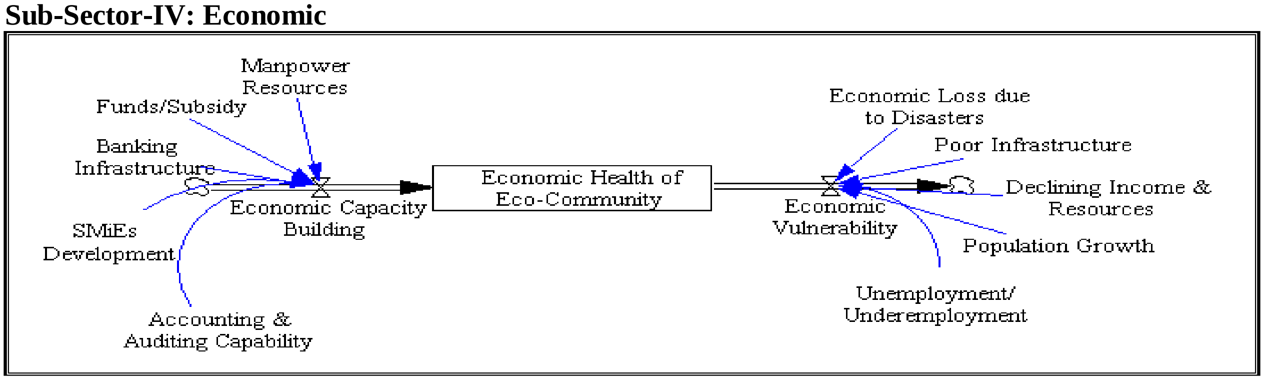


Figure 3: Humanitarian Supply Chain Capacity Building Vs Vulnerabilities Model

These sub-sector models can again be adjoined and integrated though identified causal linkages distributing varying positive (reinforcing) and negative (balancing) influences (Figure 4)-

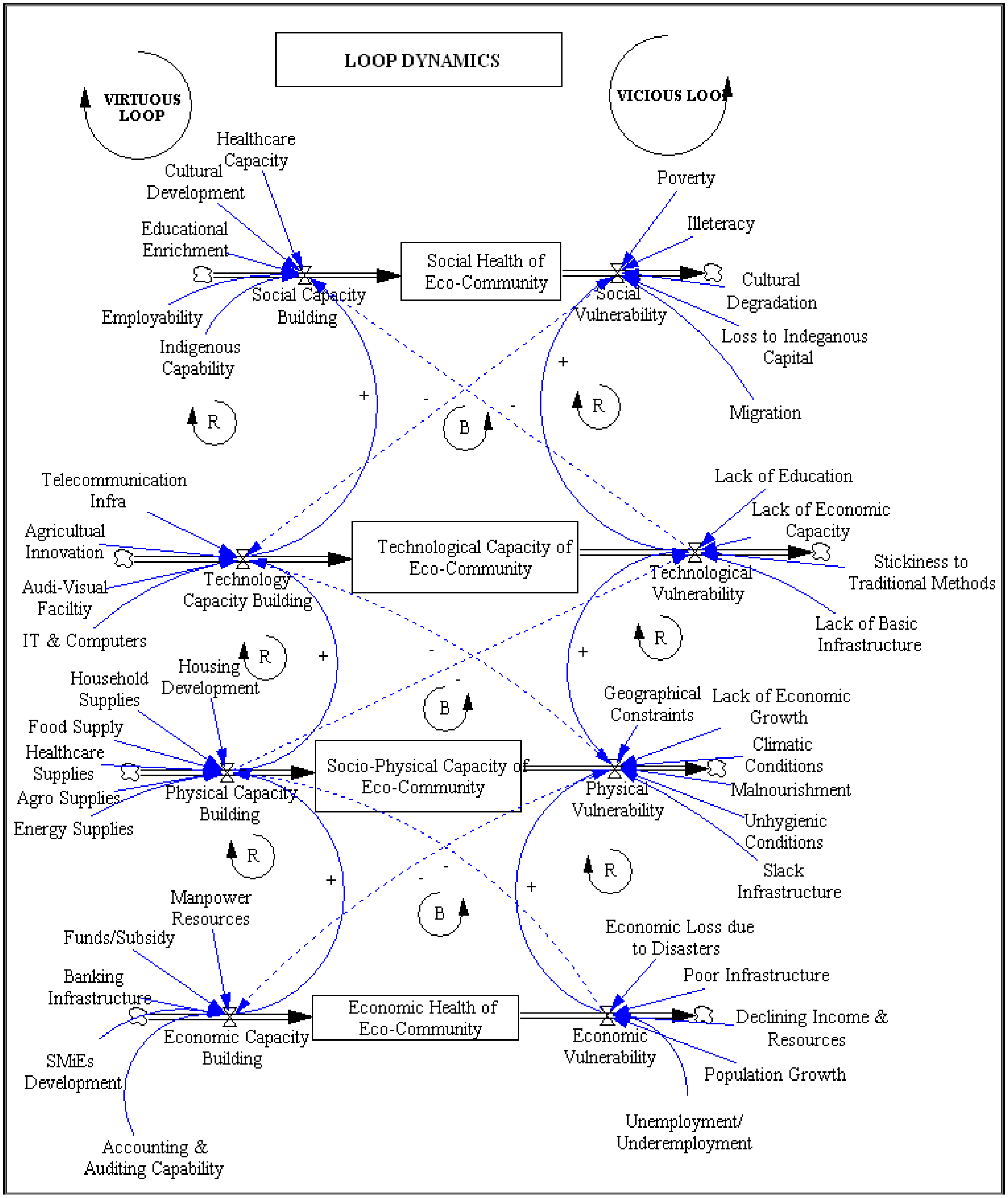


Figure 4: Integrated Stock-Flow Model of Humanitarian Supply Line

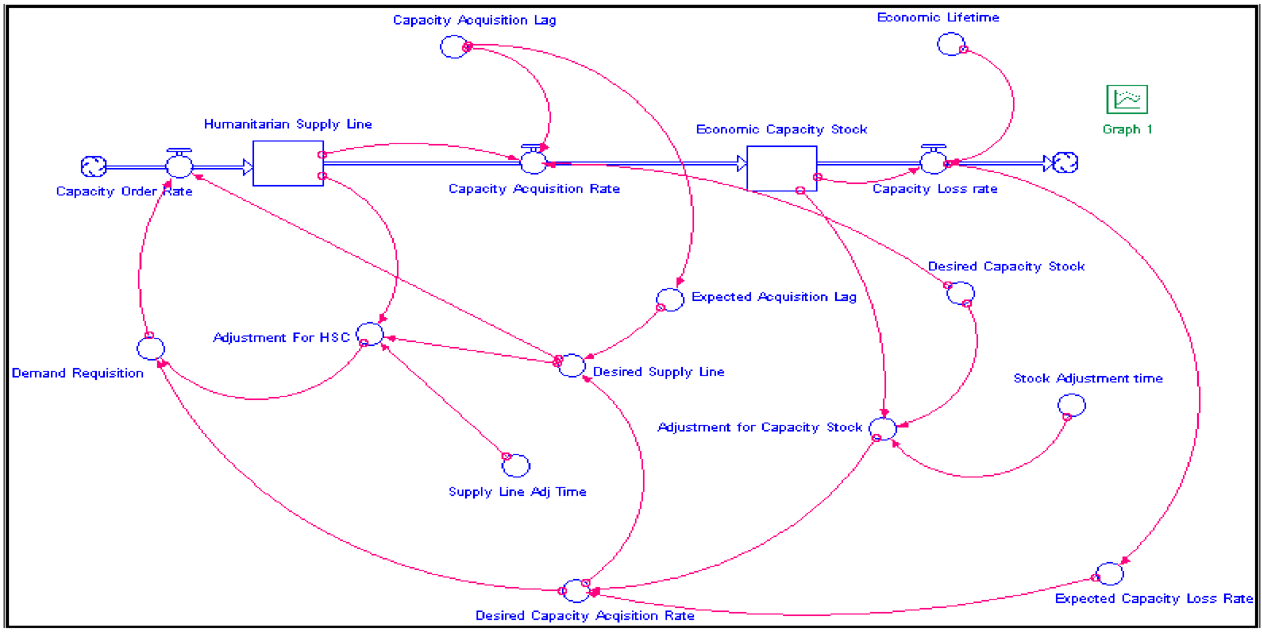
It can be visualized in this model that the increasing instances of numerous causes of vulnerabilities on the right hand side of the humanitarian supply chain model present a serious threat to the efficiency and resilience of the same. This necessitates concept building and systems that can identify these vulnerabilities early in the supply chain planning and react aggressively to their detrimental causal effects. To this end, a dynamic model developed above describes the inherent basic cause-effect relationship between the supply-side and the consumption (loss) side of the humanitarian supply chain for Eco-communities. One set of causal effects which is producing desirable effect for capacity building can be termed as virtuous causality (on the left side of model), whereas, the other set producing undesirable and counter-balancing causality (on the right side of model) can be designated as vicious causality.

Section-II

In this section, an attempt has been made to develop a simulation ready model of humanitarian supply chain to capture certain endogenous and exogenous dynamics of the system under investigation. Though, it was not found feasible to do it for the entire holistic model created in the previous section for the paucity of relevant data. Hence, we have limited our effort to develop a base model for the Economic Sub-sector of HSC supported by the Government assistance program for the Indian tribal communities budgeted for the financial year 2013-2014. It was also considered useful to use a set of additional aiding variables with their quantized values provided by research agencies (Figure 5, Table 1) in order to create a complete supply, consumption and demand scenario.

The key motivations to select tribal regions for our model was that there are thoughtfully crafted developmental programs under India Eco-Development Project (IEP) for Tribal Communities. These programs support the supply of physical infrastructure needs as well as economic needs of the community. Some of the infrastructure activities relate to housing, drinking water, schools, and other amenities whereas on the economic front, activities undertaken are distribution of livestock, providing employment for forestry works, subsidy programs etc. However, the effectiveness of these initiatives were recently surveyed to be far from adequate where the project objectives of creating sustainable alternatives and reducing the dependency on the biomass cannot be fulfilled at the present intervention levels. Hence, the current modeling approach aims to explore new insights of Humanitarian supply of various economic capacity building measures with a dynamic perspective and identify crucial intervention decision points under different scenarios.

Sub-Sector-IV: Economic Capacity Building Model for Indian Tribal Community (Base Year 2013-2014):



(Modeled in Stella Software)

Figure 5: Base Model: Economic Sub-Sector of Humanitarian Supply Line

Table 1:

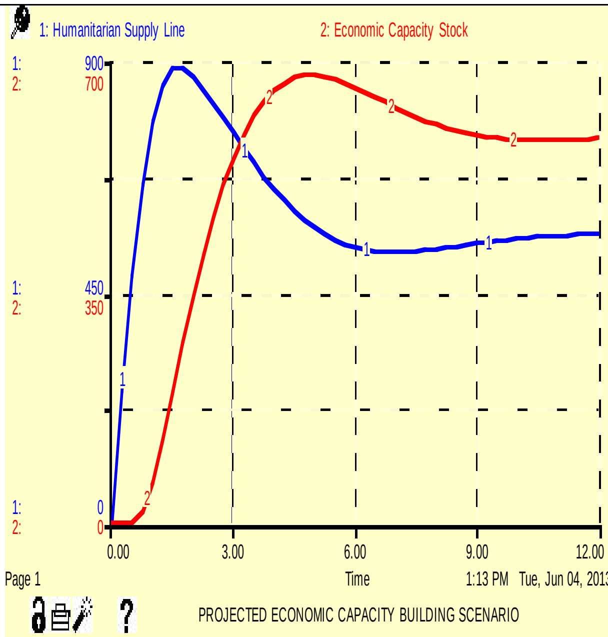
Parameters	**Values**
Capacity Acquisition (Infrastructure) Lag- India	1.5 Years (McKinsey Report 2009)
Economic Lifetime Value **(HDI-Consumption @ minimum 20% of total per year)***	5 Years (UNDP Report 2011)
Desired Economic Capacity Stock (Budgeted allocation to India Tribal Sub-plan, 2013-2014)	254.98 Billion Rupees (Indian Budget 2013)
Capacity Stock Adjustment Time (Calculated)	2 Years (based on Acquisition lag)
Humanitarian Supply Line Adjustment time (Calculated)	2 Years (based on acquisition lag)

*Inequality-adjusted HDI estimates for backward Indian states facilitate quantification of the potential loss due to inequality with respect to access to education and health.

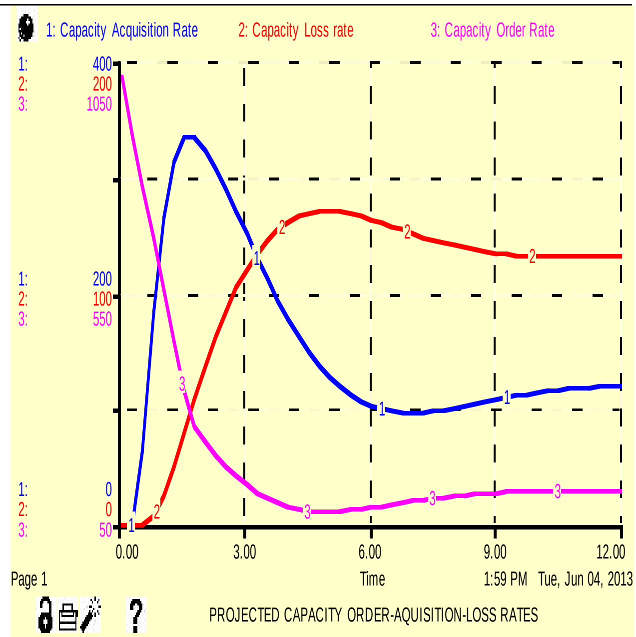
In the present model, we have identified key auxiliary variables like Capacity acquisition lag, economic lifetime (consumption propensity), capacity stock and supply line adjustment time, as they represent the greatest challenge for humanitarian aid and development assistance under extremely complex economic and social structure of undeveloped eco-communities located across Indian states.

Discussion on Simulation Results: Base-Model

Humanitarian economic assistance in the form of funds, subsidy support, infrastructure development, indigenous industries promotion etc. plays a key part to construct a community's economic capacity, particularly in the aftermath of a disaster. This assistance ensures that the community can develop, instead of sliding back into the vicious trap of vulnerabilities. Seeing the simulation behavior of the base model for economic sub-sector under initial condition, we get to understand that with the present, but, perennially maintained quantum of humanitarian supply of economic inputs to the Indian tribal regions; they can go on building their economic capacity and create a positive surplus by the 12th year (Yr. 2025); as indicated by intersecting point in the simulation Graph 1. Afterwards, even with relatively lower quantum of humanitarian supplies, these communities can remain substantially developed and may also become self-sustained at a later stage.

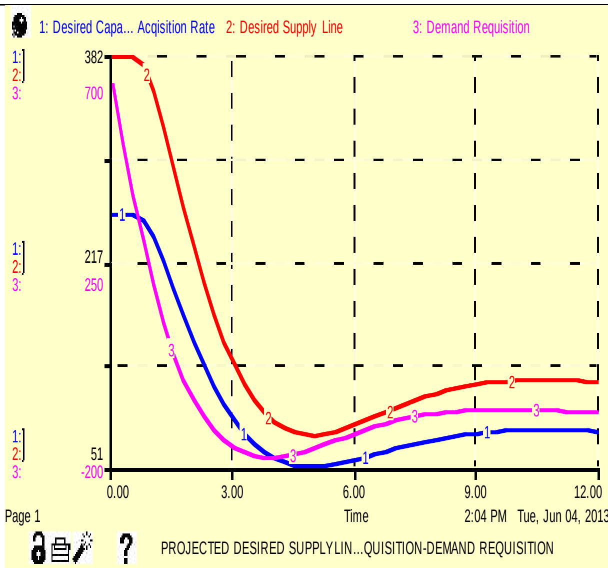


Graph 1: PROJECTED HSC & ECONOMIC CAPACITY

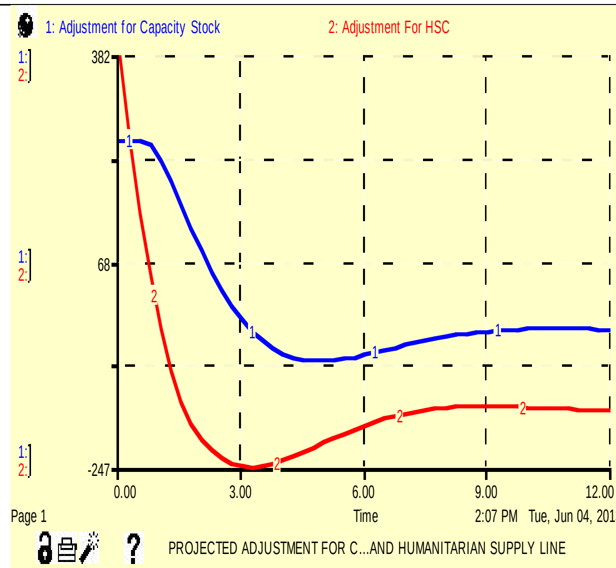


Graph 2: PROJECTED CAPACITY ACQUISITION-ORDER-LOSS (Utilization) RATES

Maximum Economic Capacity : Rs. 678 Billion
Maximum HSC Supply Line : Rs. 887 Billion
Efficiency: 76%



Graph 3: PROJECTED DESIRED SUPPLYLINE-DESIRED ACQUISITION RATE-DEMAND REQUISITION



Graph 4: PROJECTED ADJUSTMENT CAPACITY STOCK-SUPPLY LINE

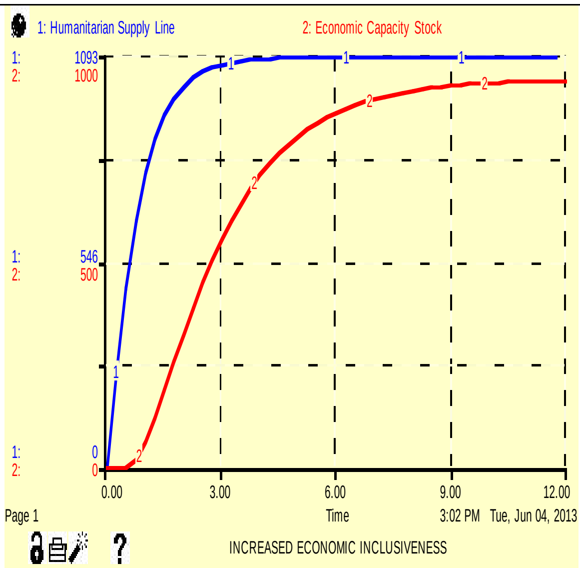
This is further corroborated by seeing the dynamic time-behavior of auxiliary variables like capacity acquisition, order and loss (consumption) rates in simulation Graph 2, desired supply line, acquisition rate and demand requisition patterns in simulation Graph 3 and finally, in the projected values for adjustment in capacity stock and humanitarian supply line depicted in the simulation Graph 4. Under the base simulation, we also analyze the efficiency value of humanitarian supply chain with respect to economic capacity building being maximum 76%, given the fact that the economic capacity is realized with some delay due to lag in acquisition and lower economic life time (consumption) rate.

Analyzing this, here, it should be understood that, an effective and timely humanitarian supply operation and its productive consumption has the capacity to save thousands of lives (Branczik 2004). It is also, however, possible that potential beneficiaries may be located within a zone of disaster or in areas with very poor infrastructure, making it difficult and dangerous for humanitarian agencies to deliver assistance (www.beyondintractability.org). Hence, as a result, one must endeavor to increase the efficiency of humanitarian supply by either increasing the utilization or consumptive capacity of target regions corroborated with decreased capacity acquisition lag or also by decreasing economic stock and supply adjustment times. These scenario effects can be simulated and observed behaviors may provide valuable insight to policy makers for better decision making.

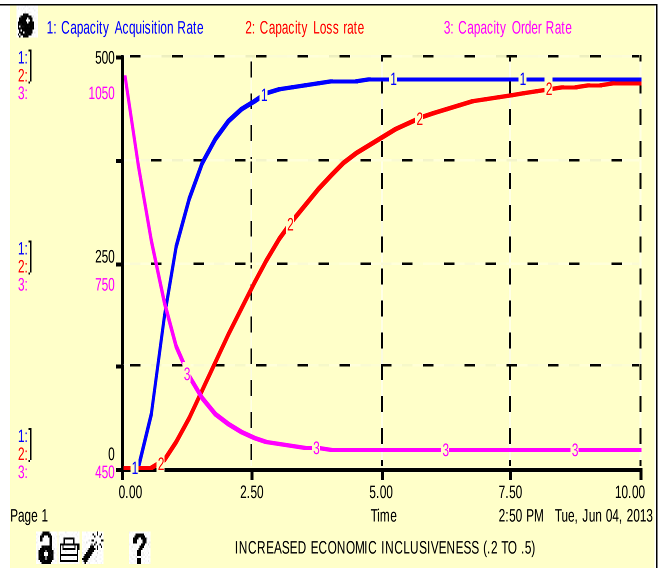
In this backdrop, the following section describes various presumptive scenarios and their respective dynamics indicating the scope of overall performance improvement.

Section-III

Scenario 1: Increased Consumption of Economic Capacity (Economic Inclusiveness) from Current minimum 20% to India average 50%*:



Graph 5: Economic Capacity-Supply Line



Graph 6: Capacity Acquisition-Capacity Order-Capacity Loss (Utilization) Rate

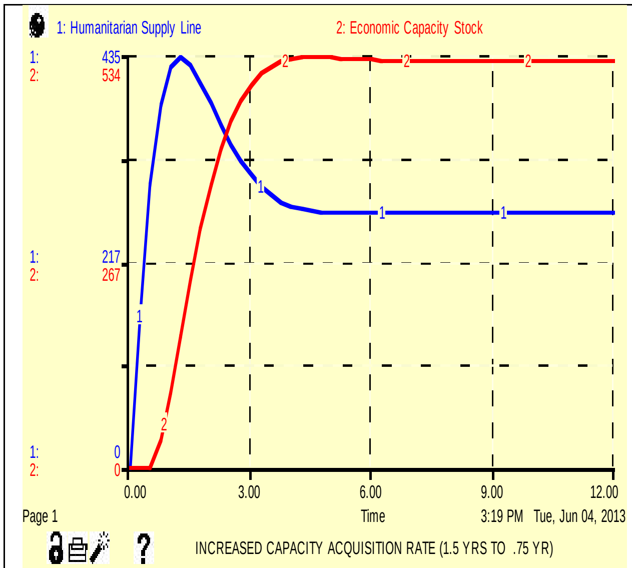
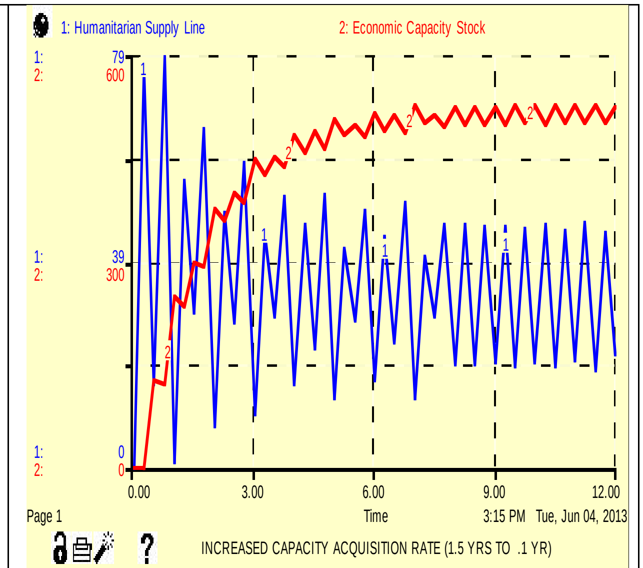
Maximum Economic Capacity: 944 Billion
Maximum HSC Line: 1092 Billion
Efficiency: 86%

***India has an average Country HDI value (using international goalposts) of 0.504 – UNDP 2011**

Under this scenario, by increasing the consumptive capacity of tribal regions from current minimum 20% to 50%, we can see the improvement in the maximum efficiency value from earlier 76% to 86%. However, one should accept that this rapid expansion of economic consumption can only be realized by a synchronized stream of consumption of social, physical and technological resources in a holistic sense as modeled and suggested in the section-I of this paper. We can further observe the corroborative behavior pattern of capacity acquisition, order and loss (consumption rates, where, as the acquisition and consumption rates are moving higher and reaching the plateau, there is corresponding declining movement of newer capacity order rate, suggesting that the community is increasingly becoming self-sustained; an idea propounded in the base model simulation of the previous section.

Scenario 2: Decreased Capacity Acquisition Lag Value

As a stand alone measure, the system performance can also be substantially improved by adjusting the capacity acquisition lag value from current base model value of 1.5 years to half of it i.e. .75 years (Graph 7).

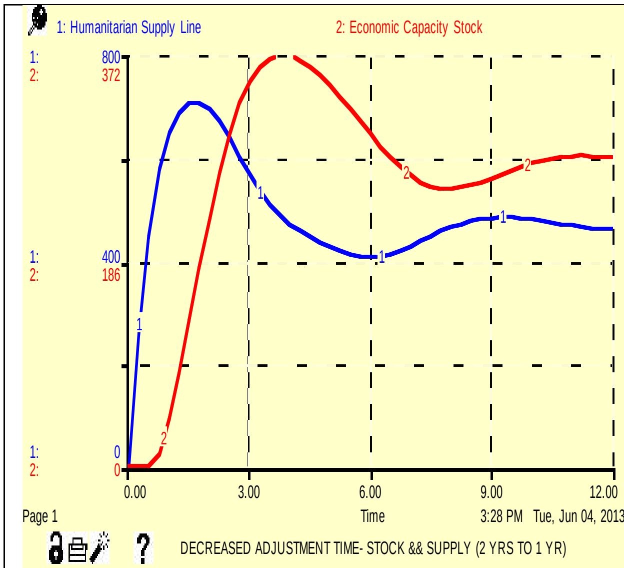
	
Graph 7: Acquisition Lag: .75 years **Maximum Economic Capacity Value: 534 Billion** **Maximum HSC Supply Value: 434 Billion**	**Graph 8: Acquisition Lag: 0.1 Year** **Maximum Economic Capacity Value: 531 Billion** **Maximum HSC Supply Value: 79 Billion**

One noticeable change is that, once, we decrease the acquisition lag value to the minimum possible value of .1 Year, we find a dramatic reduction in the expected quantum of humanitarian supply from maximum 434 billion in the previous scenario to maximum 79 billion. It goes on to prove that, with faster acquisition rate triggered due to reduction in lag time, comes an ease of supply liquidity putting lesser burden on the donor agencies and government to arrange for the required economic resources. Hence, the created pattern is oscillatory in appearance (Graph 8), indicating the short-termed synchronized lean sequences of smaller quantity supplies and corresponding faster capacity consumption.

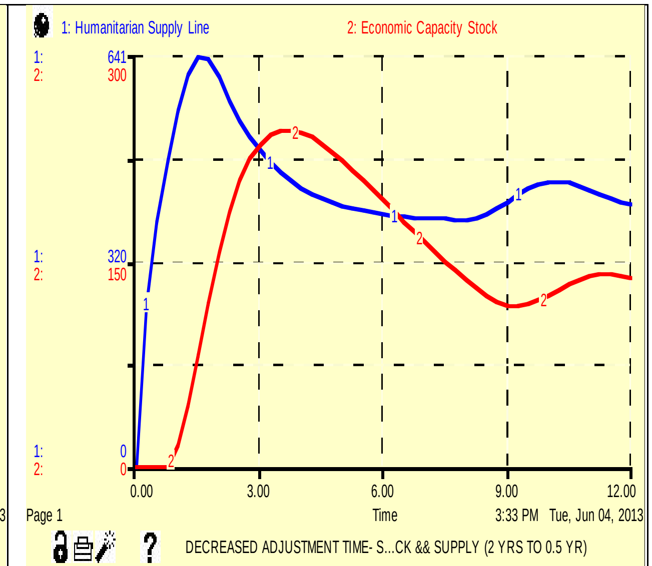
If pragmatically attainable, this scenario will effectively fill some of the critical supply-demand gaps in the humanitarian supply system. It will strengthen the coordination and capacity of donor institutions to deliver appropriate, quick, high quality aid, by making resources available in a shorter span of time. It hereby also aims to increase the standing capacity in order to mount immediate responses, and increase the competencies of supporting network agencies within the economic supply sector at both the national and local levels. Not to mention that, it may also facilitate to strengthen humanitarian logistics systems to improve the efficiency of tracking the storage, transport and distribution of relief items.

Similar benefits can also be garnered through an effective adjustment of stock and supply time, as done in the following scenario.

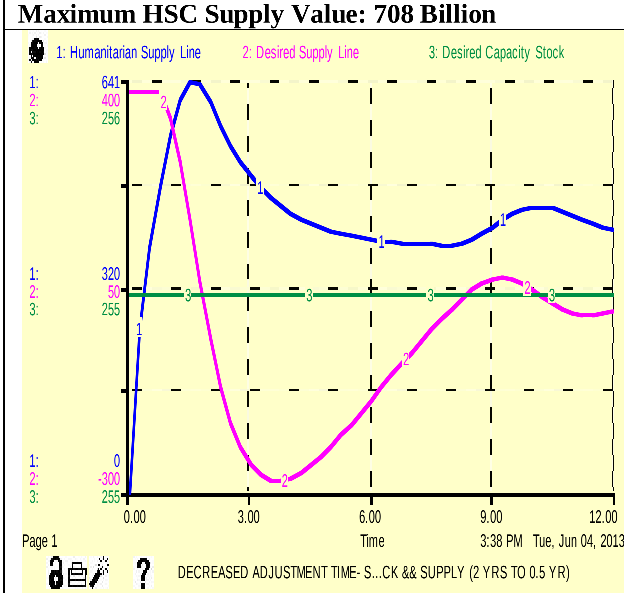
Scenario 3: Decreased Stock Adjustment and Supply-Line Adjustment Time jointly from 2 Years to 1 Year and 0.5 Year:



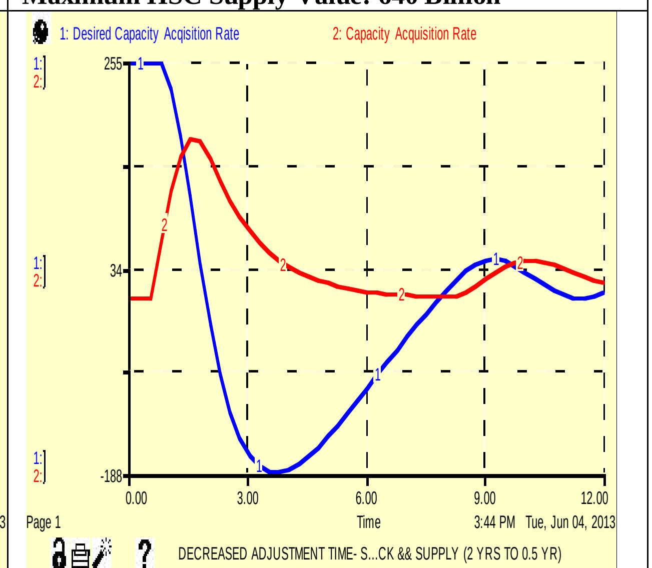
Graph 9: Adjustment Time (Stock & Supply) : 1 Year
Maximum Economic Capacity Value: 372 Billion
Maximum HSC Supply Value: 708 Billion



Graph 10: Adjustment Time (Stock & Supply) : 0.5 Year
Maximum Economic Capacity Value: 246 Billion
Maximum HSC Supply Value: 640 Billion



Graph 11: Desired Capacity Stock- Desired Supply Line



Graph 12: Desired Capacity Acquisition Rate- Actual Capacity Acquisition Rate

Under this operational experiment, the effect of stock and supply adjustments at varying rates of 1 to 0.5 years can be observed in terms of change in the patterns of economic capacity stock and humanitarian supply level over time (Graph 9-10). Interestingly, we can also see a somewhat convergence of desired supply line and actual supply line over a long haul, while the value of desired capacity being kept constant (Graph 11). Similar behavior is also observed in case of the desired capacity acquisition rate vis-à-vis the actual capacity acquisition rate (Graph 12). Our thought here is that, this scenario can be attained through the effective coordination between de-centralized agencies responsible for delivery of humanitarian supply services by a central and common command administrator introducing uniform and agile supply chain practices. This scenario can be realized by leveraging a completely IT enabled supply network with the central administrator at its top ensuring standardized supply and service activities delivered to target beneficiary communities.

Conclusion:

Humanitarian Supply Chain (HSC) is central to any developmental initiative for capacity building in the backward eco-communities of India, particularly those which are located in the disaster prone regions. Apart from providing immediate relief assistance at the incidence of natural disasters, what is more critical is their long term capacity building with a holistic perspective. This is required to enhance the effectiveness and speed of community response for major humanitarian programs, such as health, food, shelter, water, and sanitation. We can thus say that the success of short-term relief work lies in the long-term capacity building and, is critical to the performance of both current and future humanitarian operations and programs. The scenarios studied in this paper are with respect to those crucial decision environments and their underlying complexities which create an inherent endogenous dynamics perpetuated by various stakeholders giving functional response towards the humanitarian supply chain.

Some key findings of this study can be highlighted as-

- Development of a systems model of Humanitarian Supply Chain with the central goal of long-term capacity building in backward eco-communities of India
- Identification of loop-dynamics generated by mutual interplay of various factors at the sub-sector levels
- Creation of a base model of Economic sub-sector of HSC with reference to Indian Tribal communities
- Generation of various scenarios and understanding their behavioural performance over time
- Identification of crucial intervention-points by the administrator agency for improving the network output of overall Supply chain.

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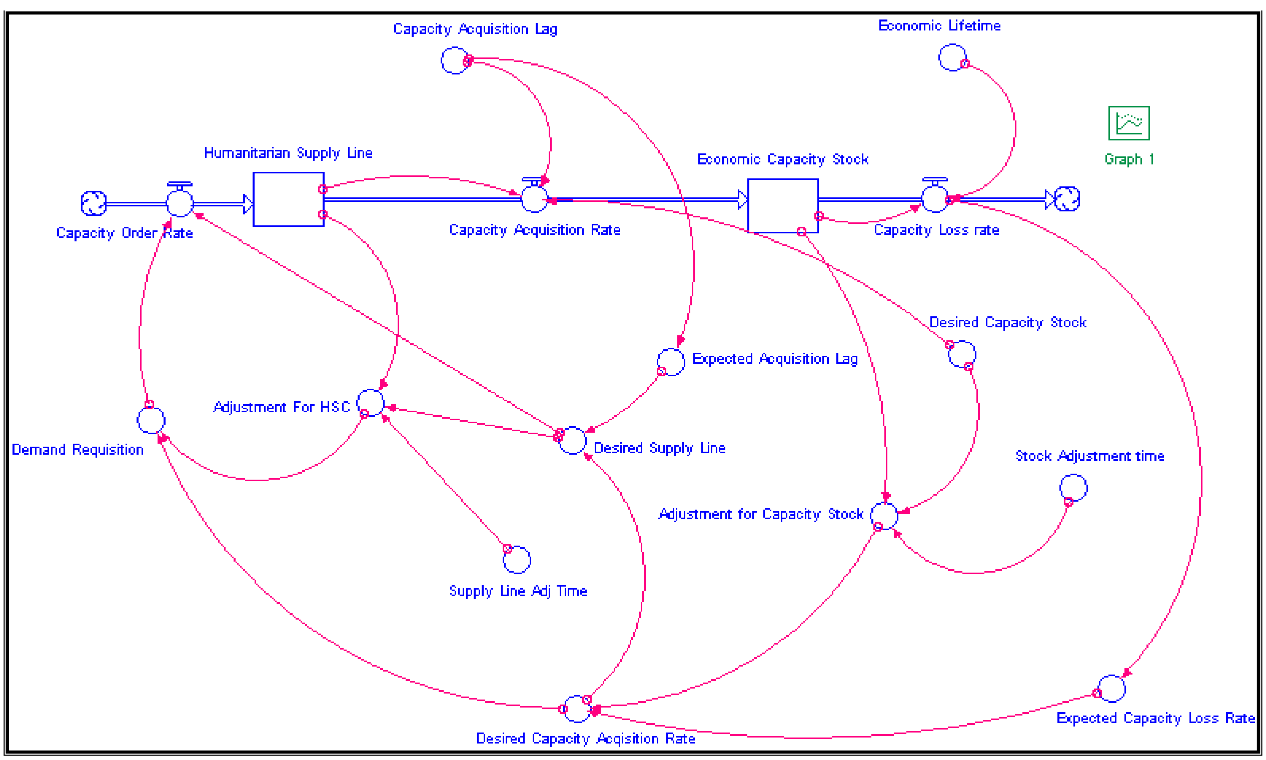
Appendix: Base Model (Economic Sector)



System Equations:

Economic_Capacity_Stock(t) = Economic_Capacity_Stock(t - dt) + (Capacity_Acquisition_Rate - Capacity__LossRate) * dt

INIT Economic_Capacity_Stock = 0

INFLOWS:

Capacity_Acquisition_Rate = (Humanitarian_Supply_Line/Capacity_Acquisition_Lag)-Desired_Capacity_Stock

OUTFLOWS:

Capacity__LossRate = Economic_Capacity_Stock/Economic_Lifetime

Humanitarian_Supply_Line(t) = Humanitarian_Supply_Line(t - dt) + (Capacity_Order_Rate - Capacity_Acquisition_Rate) * dt

INIT Humanitarian_Supply_Line = 0

INFLOWS:

Capacity_Order_Rate = MAX(0, Demand_Requisition)+Desired_Supply_Line

OUTFLOWS:

Capacity_Acquisition_Rate = (Humanitarian_Supply_Line/Capacity_Acquisition_Lag)-Desired_Capacity_Stock

Adjustment_for_Capacity_Stock = Desired_Capacity_Stock-Economic_Capacity_Stock/Stock_Adjustment_time

Adjustment_For_HSC = Desired_Supply_Line-Humanitarian_Supply_Line/Supply_Line_Adj_Time

Capacity_Acquisition_Lag = 1.5

Demand_Requisition = Desired_Capacity_Acqisition_Rate+Adjustment_For_HSC

Desired_Capacity_Acqisition_Rate = Expected_Capacity_Loss_Rate+Adjustment_for_Capacity_Stock

Desired_Capacity_Stock = 254.98

Desired_Supply_Line = Desired_Capacity_Acqisition_Rate*Expected_Acquisition_Lag

Economic_Lifetime = 5

Expected_Acquisition_Lag = Capacity_Acquisition_Lag

Expected_Capacity_Loss_Rate = Capacity__LossRate

Stock_Adjustment_time = 2

Supply_Line_Adj_Time = 2

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