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e-mail: support@smart-scm.org

тел.: (063) 593-30-41
https://smart-scm.org

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Ijaz Yusuf. Assistant Professor & Chairman of Department Operations and Supply Chain Dr. Hasan Murad School of Management, University of Management & Technology, C II, Johar Town, 54770, Lahore (Pakistan)

ORCID – 0000-0002-6938-7712
Researcher ID –
Scopus author id: –
E-Mail: ijaz.yusuf2002@gmail.com

Reznik N.P. Doctor of Economics, Professor, Professor of the Department of Management named after Professor Yosyp S. Zavadsky, National university of life and environmental science of Ukraine Kyiv (Ukraine)

ORCID – 0000-0001-9588-5929
Researcher ID – AAL-5808-2020
Scopus author id: – 57202444035
E-Mail: nadya-reznik@ukr.net

SIMPLE TO COMPLEX BUSINESS MODELS USING SYSTEM DYNAMICS LENS

Ijaz Yusuf, Nadiia Reznik. "Simple to complex business models using system dynamics lens". *System Dynamics is methodology that requires building the integrated system dynamics models using computer simulation to gain the insight of the social, economic, and business problems and keep on experimenting with the model to propose the alternative solutions to make the system better behaved.*

This paper attempts to describes the business models form simple to complex using system dynamics modeling while identifying the different facets of factory dynamics. Single stock Banana Shop to Multi-stock Complex Model Labour Intensive 3PL Logistics firm share the modelling steps and keep on adding the factory structures to make the business complex gradually. Each model helps to explore the different mode of behaviours. Production, inventory, workforce, information systems, shipments and customer orders are the dynamic variables which change over the period of time and all are interacting in the multi-stock complex 3PL logistic firm model. Model structures and interactions among of different variables not only give the model understanding but also reveal the policies to make the system better behaved. Feedback notion is other significant property for system dynamics models.

Using the factory information, its dynamics is modelled step by step and its behavior is analyzed at each stage to gain the real-life wisdom. As we keep on adding the stocks and rates to improve the model of factory dynamics, each step highlights the model insight and understanding. Model validation is done after building the model while using different tests.

Plausible policies are suggested on the basis of parametric changes and structural changes of the model that set the guidelines for policy formulation.

This model development process indicates how a Systems Dynamics model addresses the corporate issues and designs the firm of its own choice.

Keywords: Systems Thinking, Model Development, Factory Dynamics, Policy Design

Іджаз Юсуф, Надія Резнік. «Прості та складні бізнес-моделі через призму системної динаміки». *Системна динаміка – це методологія, яка вимагає побудови інтегрованих моделей системної динаміки за допомогою комп'ютерної симуляції, щоб отримати уявлення про соціальні, економічні та бізнес-проблеми та продовжувати експериментувати з моделлю, щоб запропонувати альтернативні рішення для покращення поведінки системи.*

У цій статті зроблено спробу описати бізнес-моделі від простого до складного за допомогою моделювання системної динаміки, визначивши при цьому різні аспекти заводської динаміки. Від односкладової бананової крамниці до багатоскладової складної моделі трудомісткої 3PL-логістичної фірми ділиться кроками моделювання та продовжує додавати заводські структури, щоб поступово зробити бізнес складнішим. Кожна модель допомагає дослідити різні моделі поведінки. Виробництво, запаси, робоча сила, інформаційні системи, відвантаження та замовлення клієнтів - це динамічні змінні, які змінюються з плином часу, і всі вони взаємодіють у моделі складної 3PL-логістичної фірми з декількома складами. Структура моделі та взаємодія між різними змінними не тільки дає розуміння моделі, але й розкриває політику для покращення поведінки системи. Поняття зворотного зв'язку є ще однією важливою властивістю моделей системної динаміки.

Використовуючи інформацію про фабрику, її динаміка моделюється крок за кроком, і її поведінка аналізується на кожному етапі, щоб отримати мудрість реального життя. Оскільки ми продовжуємо додавати запаси та ставки для покращення моделі динаміки заводу, кожен крок підкреслює глибину та розуміння моделі. Валідація моделі здійснюється після побудови моделі з використанням різних тестів.

На основі параметричних змін та структурних змін моделі пропонуються вірогідні політичні рішення, які встановлюють орієнтири для формулювання політики.

Цей процес розробки моделі показує, як модель системної динаміки вирішує корпоративні проблеми і проектує фірму за власним вибором.

Ключові слова: системне мислення, розробка моделей, динаміка виробництва, розробка політики.

Introduction. System Dynamics is a versatile methodology that has been used to integrate existing economic concepts into comprehensive models for providing new insights (Saeed, 2014). System Dynamics is a methodology that starts with important problems, comes to understand that structures that produce undesirable symptoms, and moves on to finding changes in structure and policy that will make a system better behaved (Forrester, 1980). System Dynamics being a blend of knowledge of control engineering, cybernetics and organizational theory is a guiding philosophy to analyze the dynamic behavior of model in terms of its feedback mechanisms (R. Geoffreycel, 1985). System thinking, in practice, is a continuum of activities which range from the conceptual to the technical (Barry Richmond, 1987). There are many steps and different phases that describe the modeling protocol. Sajjad and Yusuf (2007) has discussed the model building process as under:

	Problem Definition
Conceptual	System Conceptualization
	Model Representation
	Model Behavior
Technical	Model Evaluation
	Policy Analysis

The modeling process uses two important schemes to highlight the dynamics of system i.e. thinking about how the quantities vary through time and thinking about whether a substantial feedback relationship exists.

Reinforcing and Balancing Loops

Model is the blend of balancing and reinforcing loops. Behavior of the system is the result of interaction of balancing and reinforcing loops.

A positive loop is often defined "… by the fact that an initial change in any factor eventually induces further self-change in the original direction (Levin, Roberts & Hirsch, 1975). Representative of the definitions of negative feedback loops are the followings: "When a feedback loop response to a variable opposes the original perturbation, the loop is negative or goal-seeking (Towill, 1996). The definition of a negative loop is usually interpreted to mean that" … a change in one element is propagated around the circle until it comes back to change that element in a direction opposite to the initial change" (Meadows, 1972).

Stock and Flow Variables

Technical phase begins with level and rate variables. Feedback structure can be portrayed by equations or stock-and-flow diagrams (George P. Richardson, 1986). Stocks reflect the conditions within the system at a point in time. Stocks accumulate the flows and depending upon the rate of inflow and outflow the level of stock varies. Whereas flows represent the stream of activity associated with particular stocks. Decision rules govern the flow and stock and accordingly different modes of behaviors generate over period of time.

Presentation of the main results.

Model Development To develop the model, we have to follow the steps mentioned above, but sometimes the feedback loops are so obvious that we directly move towards stock and flow equation. The below mention models are develop using computer simulation software STELL SOFTWARE version 1.1 (Barry et al, 1987). The objective is to learn the system dynamics modeling using factory dynamics comprising so many business scenarios from simple to complex and from single stock to multiple stocks.

Single Stock Model: Banana Shop To understand the dynamic of a factory we have to explore the different business scenarios from simple to complex, the simplest work pattern is the Banan shop where an owner gets the material and to deliver the material, the simplest form of a trading firm only deals with stock of materials and incoming supplies from suppliers as a result of order placed and process of delivery the material procured against the confirmed orders from customers. If inflow and out flow is same there is no change in the stock of materials stacked if incoming supplies are more than the customer orders to deliver the product then stock of materials piled up and if the inflow of supplies is less than the customer orders then there will be more shipment and stock of materials stacked has a decreasing trend. That is quite obvious with the simple stock and flow diagram.

<u>Inflow is equal to Outflow</u>

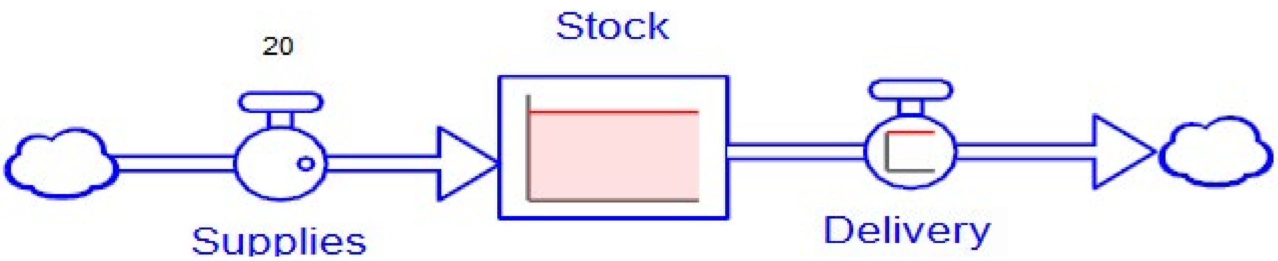


Figure 1 – Stock and Flow Diagram

Top-Level Model:
Stock(t) = Stock(t - dt) + (Supplies - Delivery) * dt
INIT Stock = 250
INFLOWS:
Supplies = 20
OUTFLOWS:
Delivery = 20
{ The model has 3 (3) variables (array expansion in parens).
In 1 Modules with 0 Sectors.
Stocks: 1 (1) Flows: 2 (2) Converters: 0 (0)
Constants: 2 (2) Equations: 0 (0) Graphicals: 0 (0)}

Inflow is greater than Outflow (from 20 units/hr to 30 units /hr)

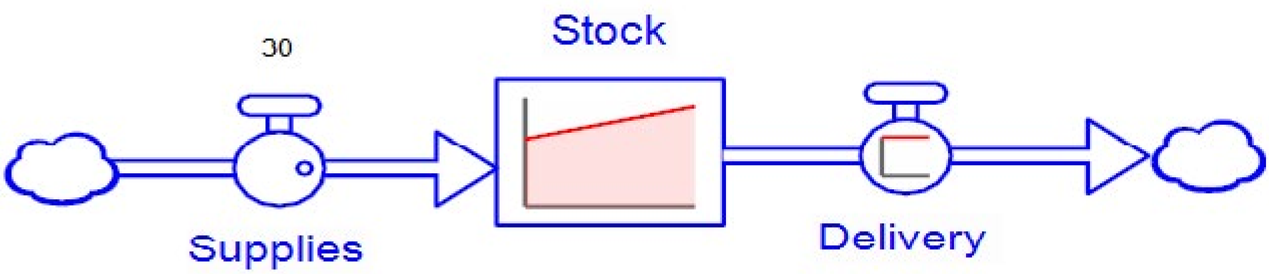


Figure 2 – Stock and Flow Diagram (Supplies greater than delivery)

Top-Level Model:
Stock(t) = Stock(t - dt) + (Supplies - Delivery) * dt
INIT Stock = 250
INFLOWS:
Supplies = 30
OUTFLOWS:
Delivery = 20
{ The model has 3 (3) variables (array expansion in parens).
In 1 Modules with 0 Sectors.
Stocks: 1 (1) Flows: 2 (2) Converters: 0 (0)
Constants: 2 (2) Equations: 0 (0) Graphicals: 0 (0)}

Inflow is lesser than Outflow (from 20 units/hr to 15 units /hr)

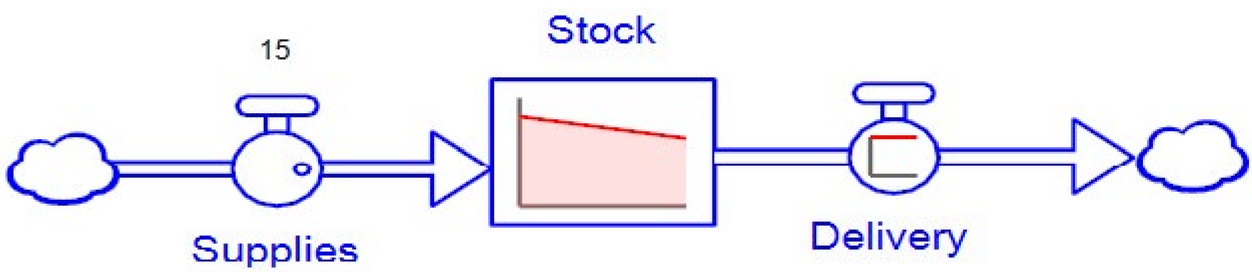


Figure 3 – Stock and Flow Diagram (Supplies lesser than delivery)

Top-Level Model:
Stock(t) = Stock(t - dt) + (Supplies - Delivery) * dt
INIT Stock = 250
INFLOWS:
Supplies = 15
OUTFLOWS:
Delivery = 20
{ The model has 3 (3) variables (array expansion in parens).
In 1 Modules with 0 Sectors.
Stocks: 1 (1) Flows: 2 (2) Converters: 0 (0)
Constants: 2 (2) Equations: 0 (0) Graphicals: 0 (0)}

No change in Stock, Increasing Stock and Decreasing Stock

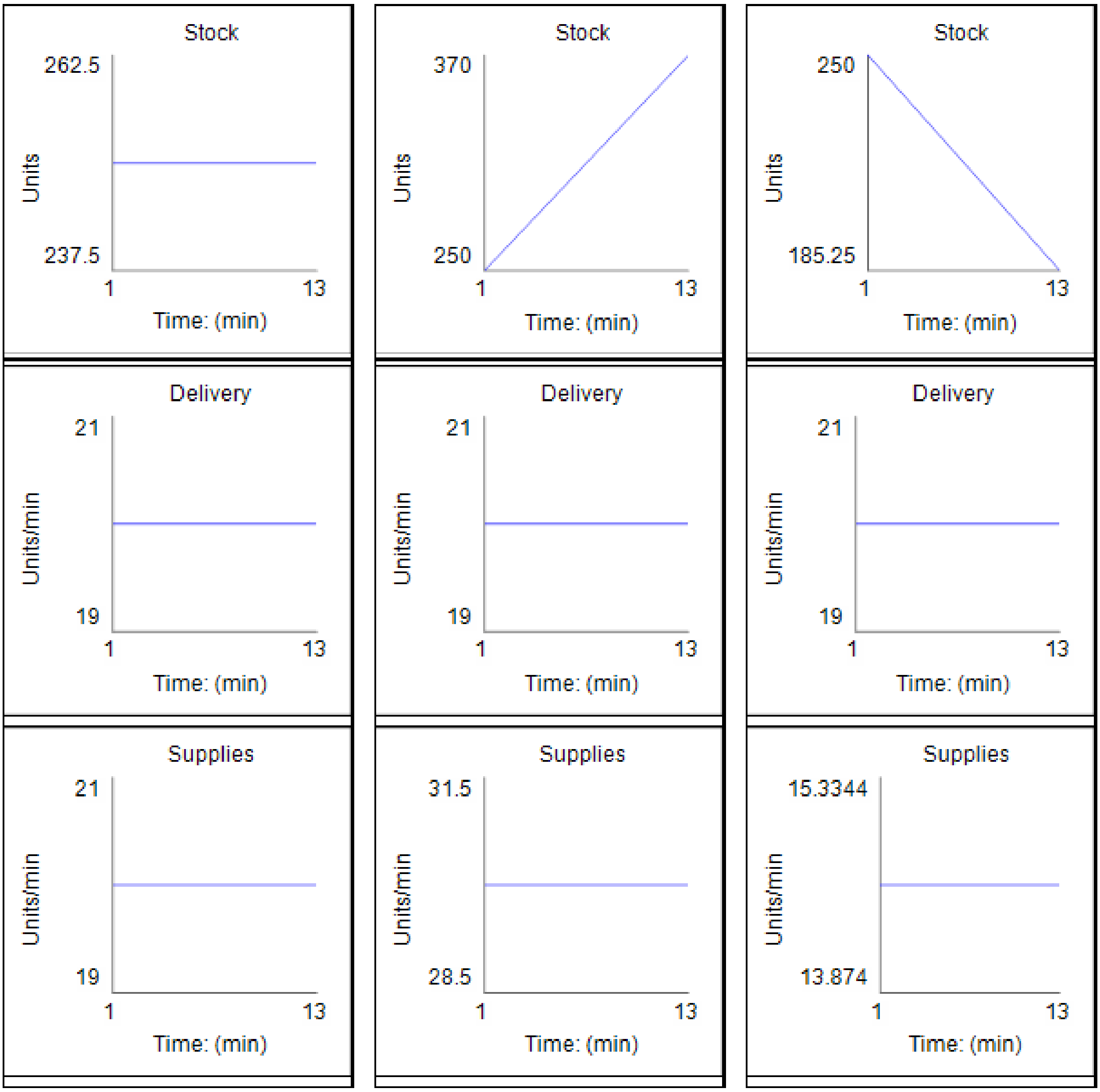


Figure 4 – Behavioural modes of Stock and Flow Model

Loop Gain = dflow/dstock
= d (producing)/d(INV)
=producing * d(1)/d(INV)
=producing * d(INV^0))/d(INV)
=producing * ($0*INV^{-1}$)
=producing * 0 =0
Loop Gain = 0
Eigen Value =0

<u>Labour based production Model: LED Bulb Manufacturing</u>

External resource production process depicts the higher level of the firm from trading to production. Now workforce is hired to produce the saleable units (LED Bulbs) and productivity of the workers is assumed that is fixed, product of workforce and labour productivity appears in the form of production rate that fills the stock of sellable units (LED Bulbs), when the production rate and shipment rate both are same, inventory of sellable units' remains constant. If the productivity of the workers is enhanced using production incentive from 100 % to 130 % then the stock has gone up if it is declined then stock has gone down.

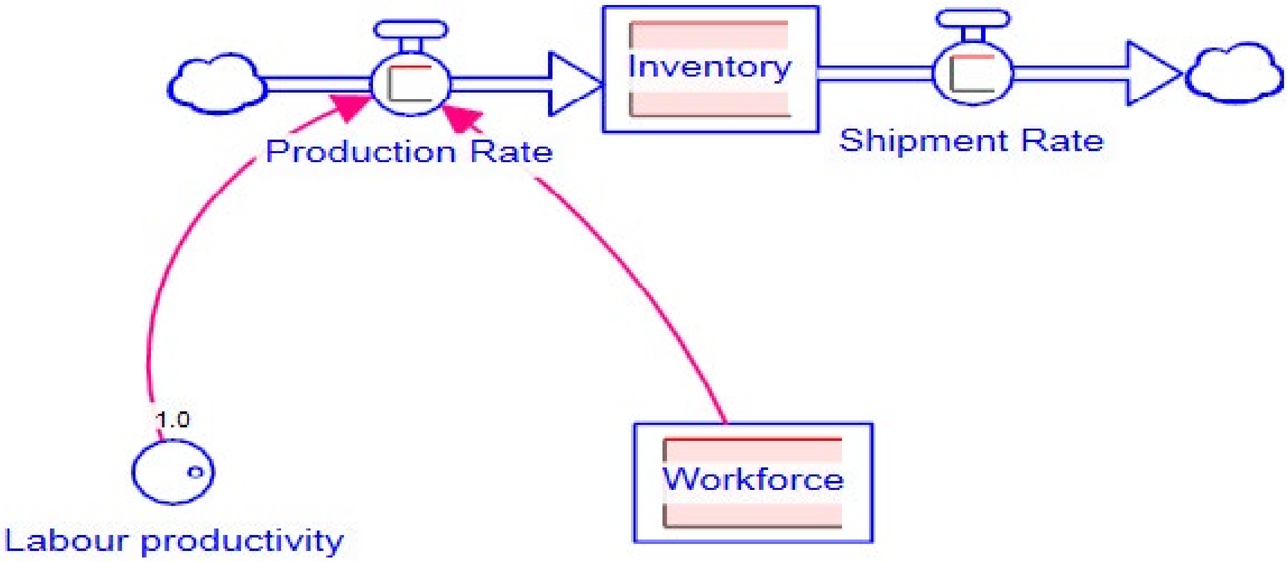


Figure 5 – External Resource Production Model

Top-Level Model:
Inventory(t) = Inventory(t - dt) + (Production_Rate - Shipment_Rate) * dt
INIT Inventory = 1000
INFLOWS:
Production_Rate = Labour_productivity*Workforce
OUTFLOWS:
Shipment_Rate = 100
Workforce(t) = Workforce(t - dt) + * dt
INIT Workforce = 100
Labour_productivity = 1
{ The model has 5 (5) variables (array expansion in parens).
In 1 Modules with 0 Sectors.

Stocks: 2 (2) Flows: 2 (2) Converters: 1 (1)
Constants: 2 (2) Equations: 1 (1) Graphicals: 0 (0) }

No change in Stock, Increasing Stock and Decreasing Stock

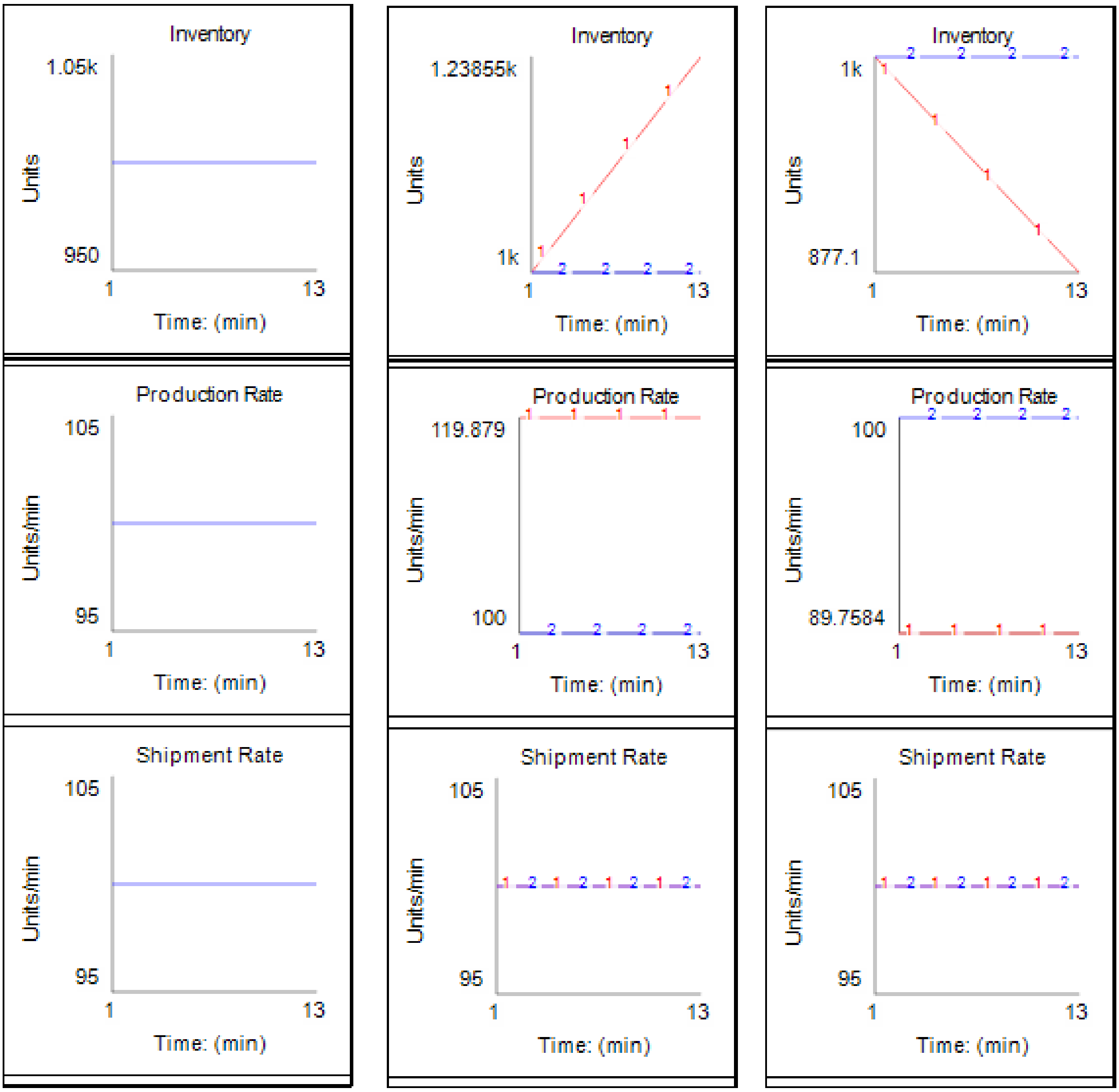


Figure 6 – Behavioural Modes of External Resource Production Model

Loop Gain = dflow/dstock

$= d\,(\text{production rate})/d(INV)$

$= d(\text{labour productivity} * \text{workforce})/d(INV)$

$= \text{labour productivity} * \text{workforce}\ (d\ 1)//d(INV)$

$= \text{labour productivity} * \text{workforce} * d\ (INV^{0})/\ (0 * INV^{-1})$

$= \text{labour productivity} * \text{workforce} * (0 * INV^{-1})$

$= \text{labour producitivty} * \text{workforce} * 0 = 0$

Loop Gain = 0

Eigen Value =0

Labour Intensive Firm (Labour Contractor for Packing candies) Model

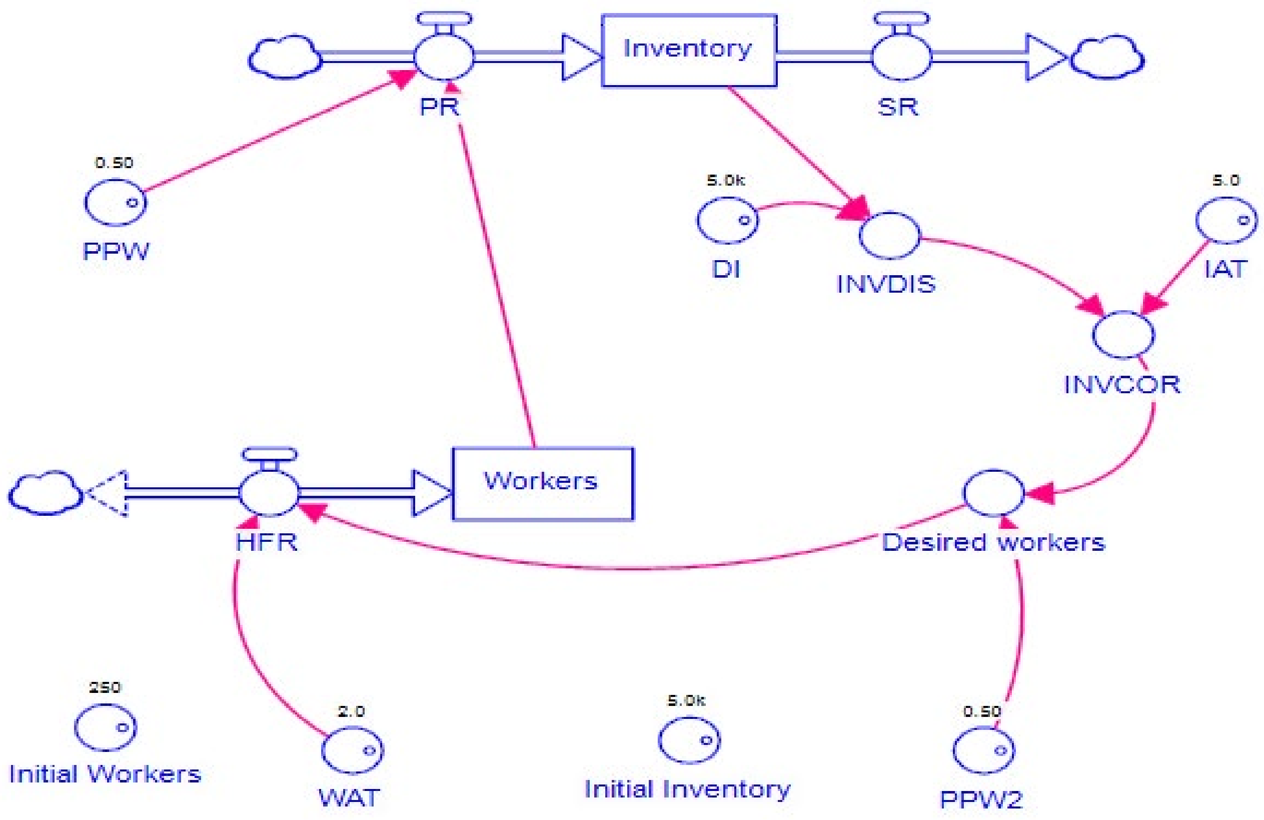


Figure 7 – Factory Dynamics of Labour based firm

Abbreviations	Descriptions	Unit of Measure
PR	Production Rate (Manual Packing the candies)	Items per day
SR	Shipment Rate (Dispatching the product to market)	Items per day
DI	Desired inventory	Number of Items
INVDIS	Inventory Discrepancy	Number of Items
INVCOR	Inventory Correction	Number of Items
IAT	Inventory Adjustment Time	Days
WAT	Workers Adjustment/Training Time	Days
HFR	Workers Hire and Fire Rate	Workers per day
EC	Equilibrium constant	Number of Items
PPW/PPW2	Labour Productivity	Items produced per worker per day

Top-Level Model:
Inventory(t) = Inventory(t - dt) + (PR - SR) * dt
INIT Inventory = Initial_Inventory
INFLOWS:
PR = Workers*PPW
OUTFLOWS:
SR = 125*(1+STEP(0.1, 5))

Workers(t) = Workers(t - dt) + (HFR) * dt
INIT Workers = Initial_Workers
INFLOWS:
HFR = Desired_workers/WAT
Desired_workers = INVCOR/PPW2
DI = 5000
IAT = 5
Initial_Inventory = 5000
Initial_Workers = 250
INVCOR = INVDIS/IAT
INVDIS = DI-Inventory
PPW = 0.5
PPW2 = 0.5
WAT = 2
{ The model has 15 (15) variables (array expansion in parens).
In 1 Modules with 0 Sectors.
Stocks: 2 (2) Flows: 3 (3) Converters: 10 (10)
Constants: 7 (7) Equations: 6 (6) Graphicals: 0 (0)}

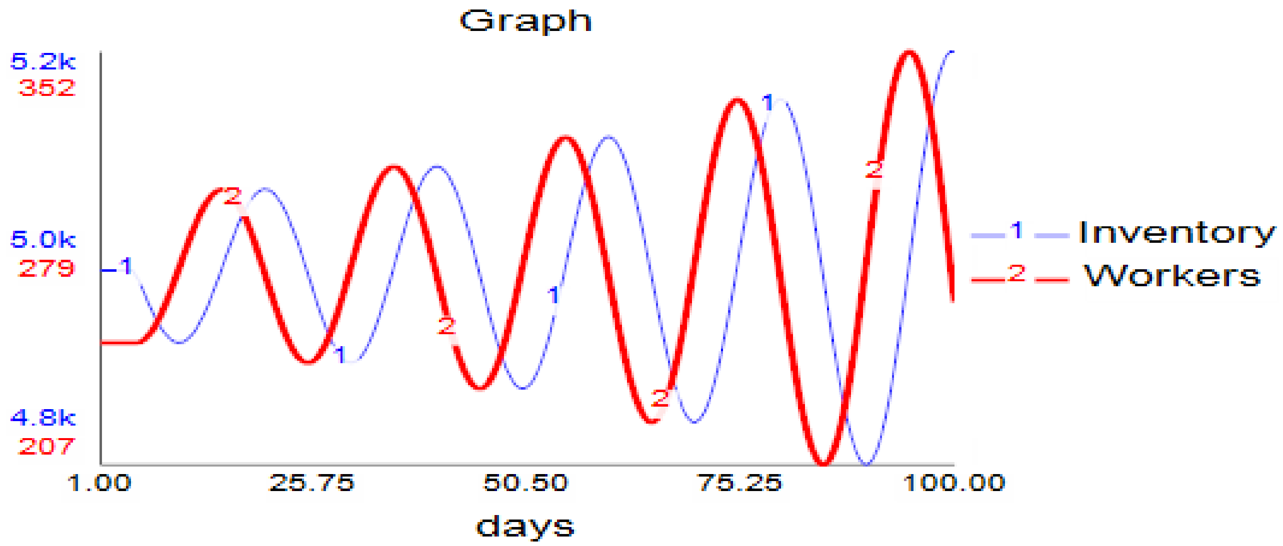


Figure 8 – Oscillatory waveform of workforce and units to be produced in a labour based firm

Loop Gain = dflow/dstock
= d (production rate)/d(INV)
=d(labour productivity * workforce)/d(INV)
= labour productivity * workforce (d 1)//d(INV)
=labour productivity * workforce * d (INV^0)/ $(0*INV^{-1})$
=labour productivity * workforce * $(0*INV^{-1})$
=labour productivity * workforce * 0 = 0
Loop Gain = 0
Eigen Value =0

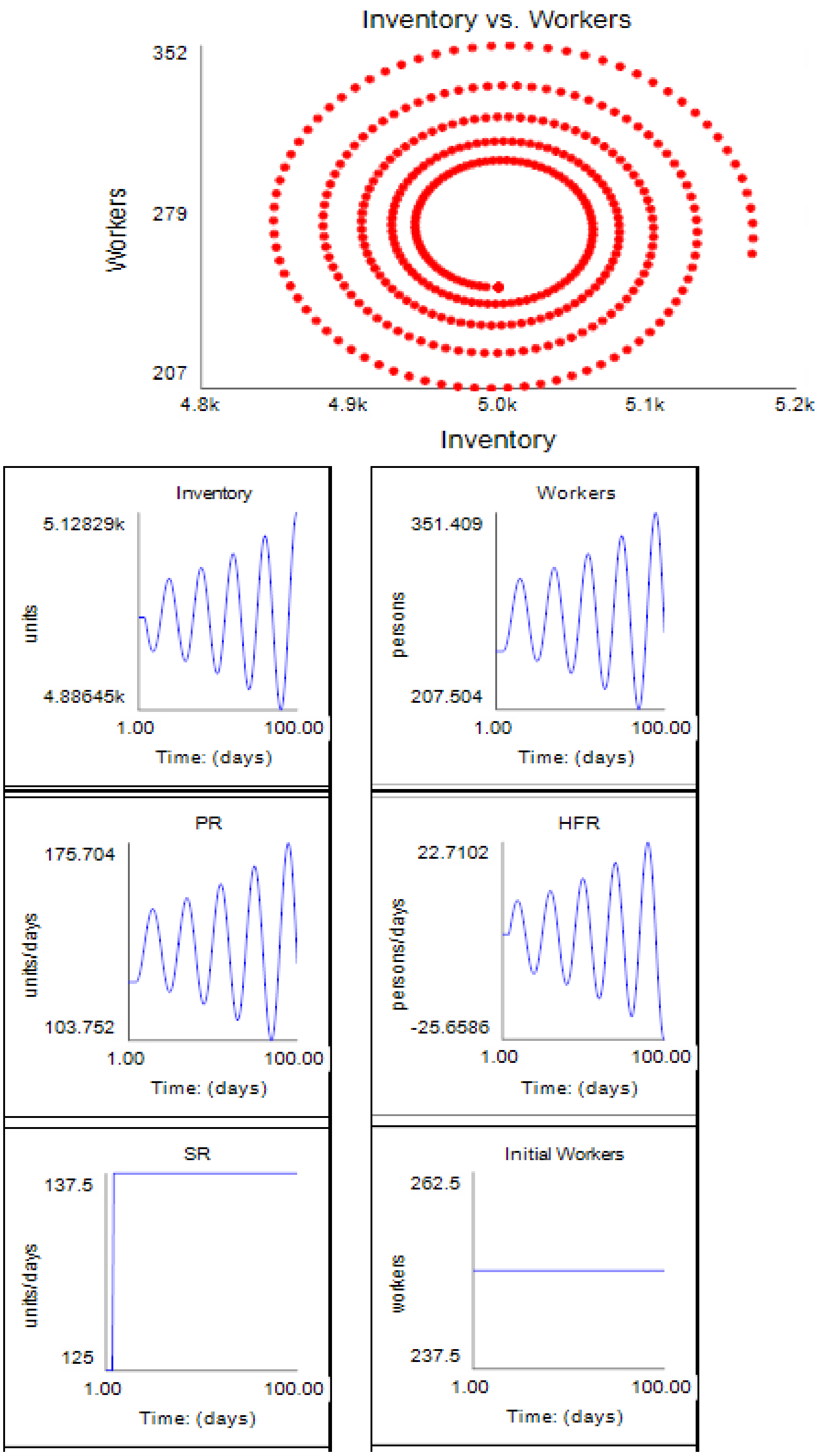
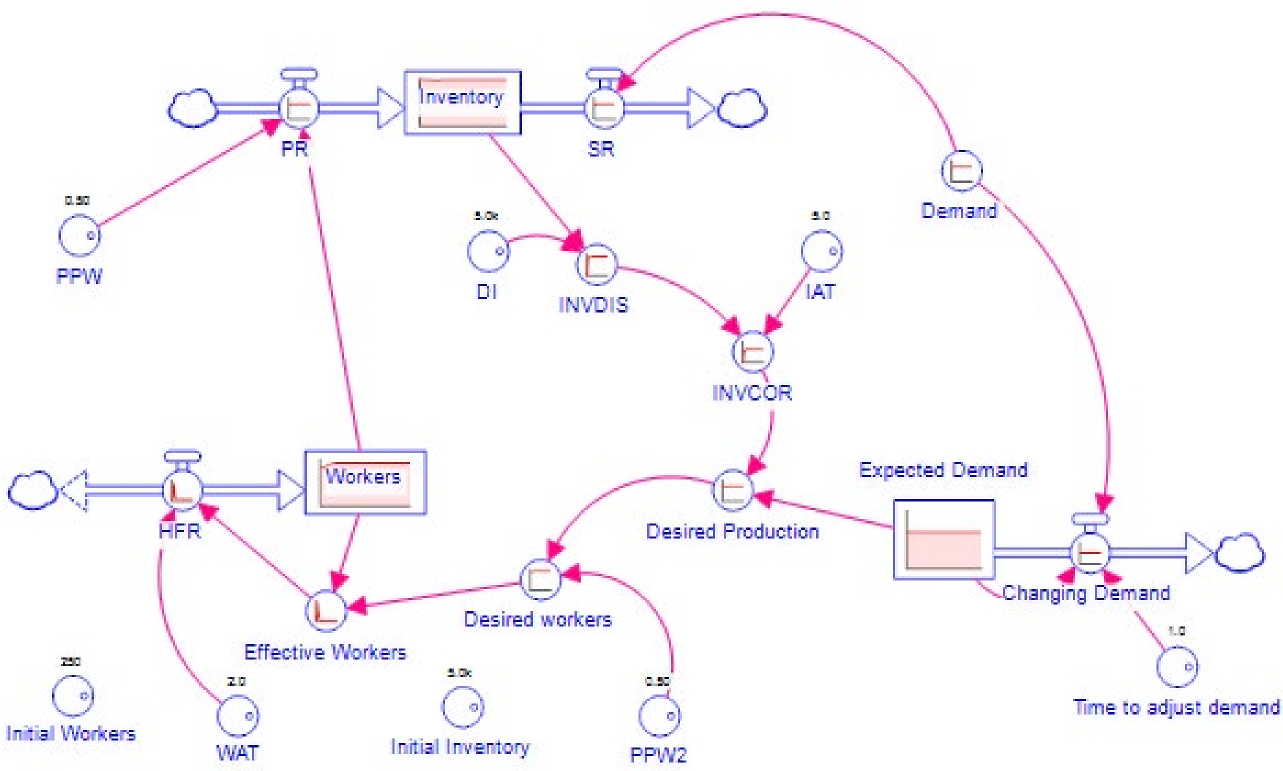


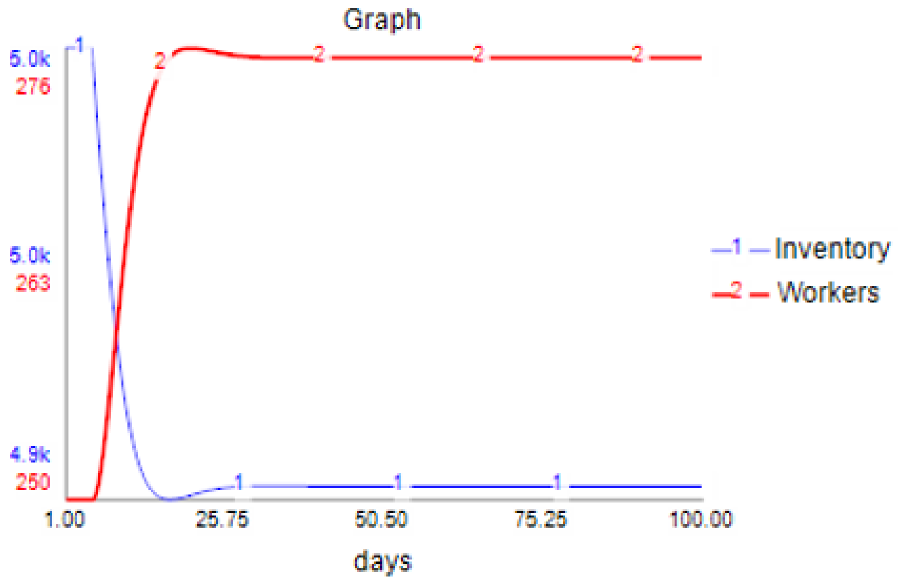
Figure 9 – Behavioural Waveform of Stock and Flow Diagram (Supplies greater than delivery)

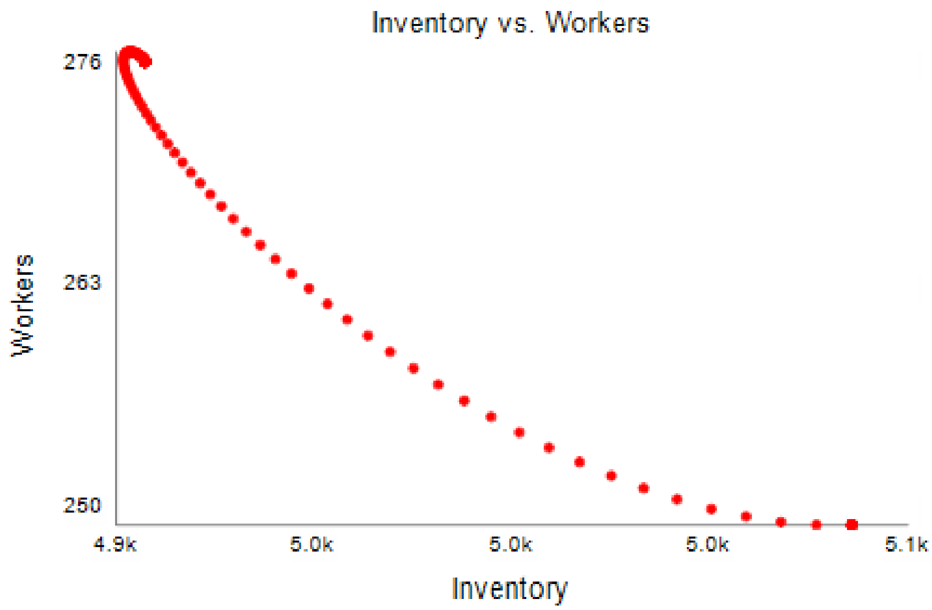
3PL Logistics Firm with Multiple Stocks: Factory Dynamics Model with Expected Demand

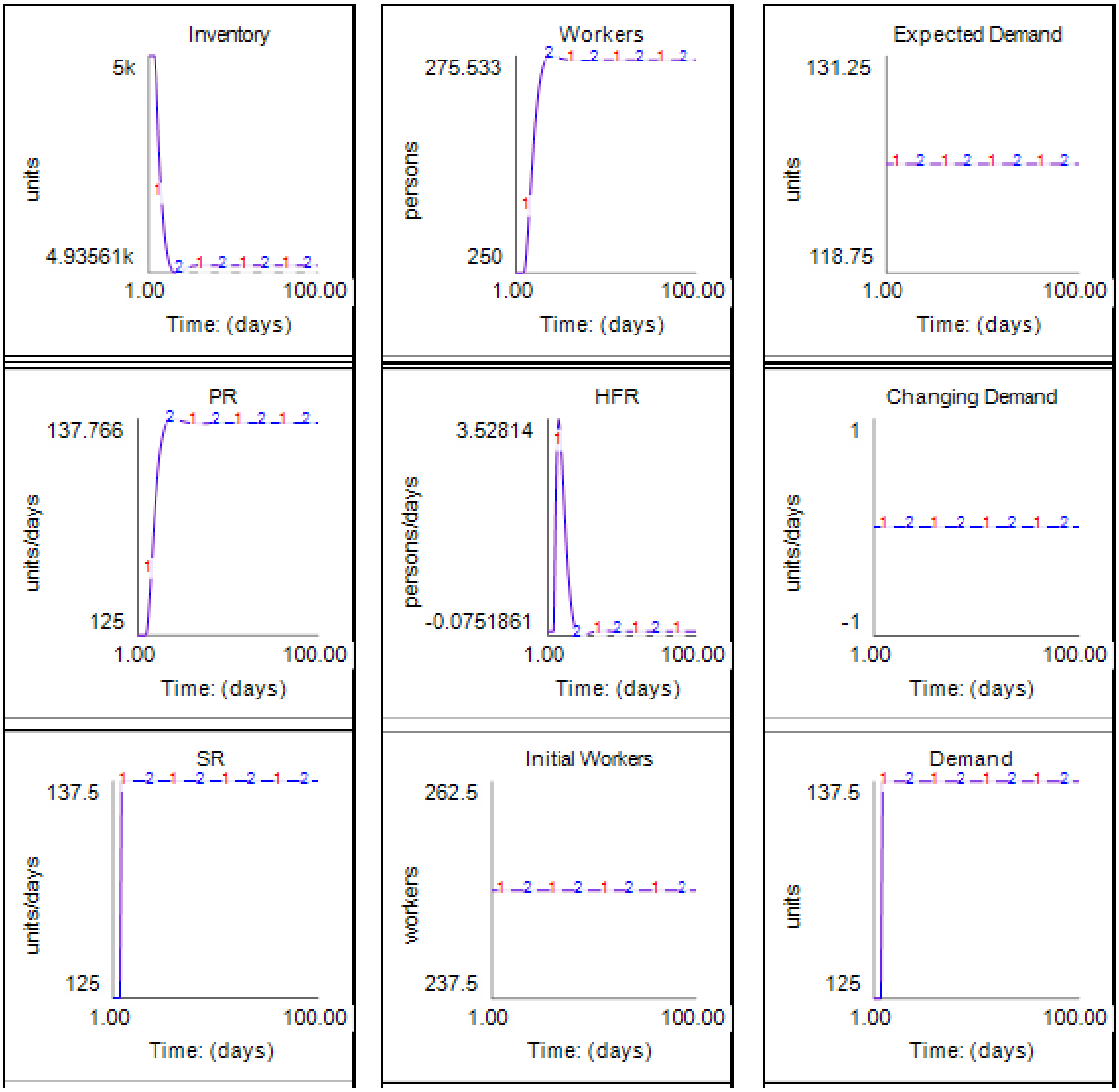


Top-Level Model:
Expected_Demand(t) = Expected_Demand(t - dt) + (- Changing_Demand) * dt
INIT Expected_Demand = Demand
OUTFLOWS:
Changing_Demand = (Expected_Demand-Demand)/Time_to_adjust_demand
Inventory(t) = Inventory(t - dt) + (PR - SR) * dt
INIT Inventory = Initial_Inventory
INFLOWS:
PR = Workers*PPW
OUTFLOWS:
SR = Demand
Workers(t) = Workers(t - dt) + (HFR) * dt
INIT Workers = Initial_Workers
INFLOWS:
HFR = Effective_Workers/WAT
Demand = 125*(1+STEP(0.1, 5))
Desired_Production = INVCOR+Expected_Demand
Desired_workers = Desired_Production/PPW2
DI = 5000
Effective_Workers = Desired_workers-Workers
IAT = 5
Initial_Inventory = 5000
Initial_Workers = 250
INVCOR = INVDIS/IAT

INVDIS = DI-Inventory
PPW = 0.5
PPW2 = 0.5
Time_to_adjust_demand = 1
WAT = 2
{ The model has 21 (21) variables (array expansion in parens).
In 1 Modules with 0 Sectors.
Stocks: 3 (3) Flows: 4 (4) Converters: 14 (14)
Constants: 8 (8) Equations: 10 (10) Graphicals: 0 (0)}







Model Validation and Testing

Validation is the process of establishing confidence in the soundness and usefulness of a model. There is no single test which serves to validate a system dynamics model rather confidence on model accumulates gradually as the model passes more tests.

Model validation is important aspect in model building process. In system dynamics there are some tests which are associated with model structures, some tests are with model behaviour and some tests are associated with policy implications.

Dimensional Consistency Test

Dimension consistency test deals with the structure of the model. The model variables must have some unit of measure and both sides of the equations must be balanced dimensionally. For example the unit of measure of the production rate must be equal to unit of measure of shipment rate and so on so forth. This test also checks whether dimensions of variables in the model correspond to the unit in which they can meaningfully express the real variables which exist in the company. In Stella Software Version 1.1 it checks automatically and where there is discrepancy it highlights for correction.

Extreme Conditions Test

Extreme condition tests also deals with the structure of the model. Whether the structure of the model is so robust or not how the model behaves under extreme condition. For example there is a labour strike and no production as a result there is no increase in the inventory. If the model behaviour depicts the real world behaviour in the same situation as model did in extreme conditions it means model satisfies the test.

Structure Verification Test

This test as well checks the structure of the model. The variables and the way the equations using variables in the model are formulated have a logical rational behind and represent the real system structure. That further enhances the confidence of the model that model is a valid model.

Behavior sensibility test

This test is focused on detecting the parameters whose small changes cause significant change in the model behavior. The fewer such parameters, the higher the credibility of the model is. However, the model behavior sensibility is acceptable if in the real system small change of the parameter values also causes significant change of the system behavior. The objective of the systems dynamics is to find the system structures that have most effect on the model behaviour. So policies can be designed either on the basis of the parametric sensitivity or on the basis of systems structures.

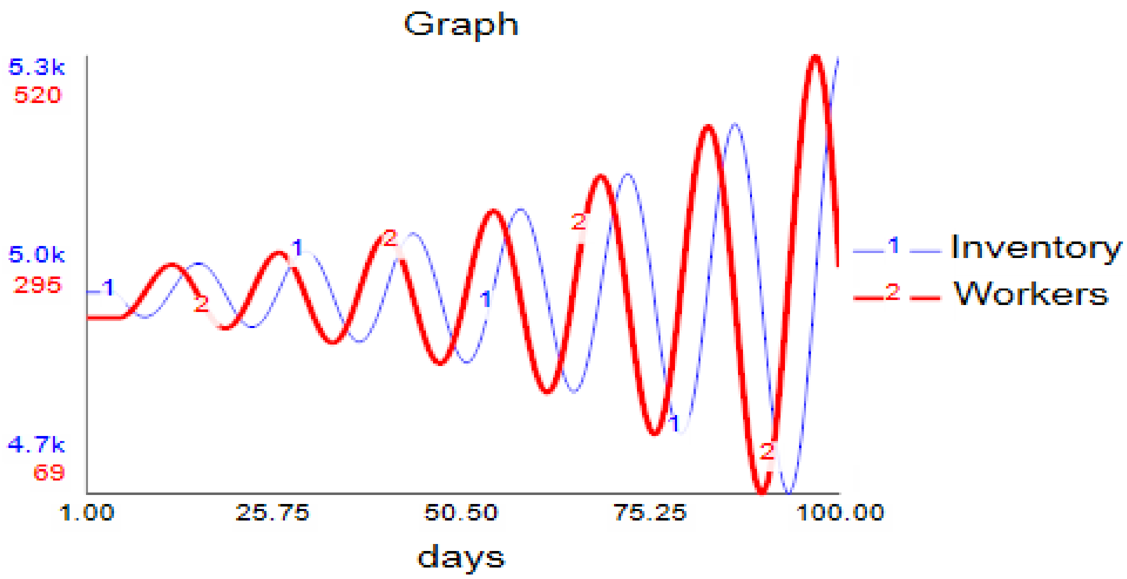
Policy Experiments

Playing with the model always helps to gain the insight about the model. Stock and flow structures are governed by the decision rules that reflect the various modes of behaviors of the model. Decision rules control the behavioural pattern and provide a baseline how policies can be proposed to make the system better behaved. Computer simulations depict the fate of the problem under study. Practitioners and experts can choose the policies that design the future of organization as per their expectations

Model Response to Policies
Parametric Base

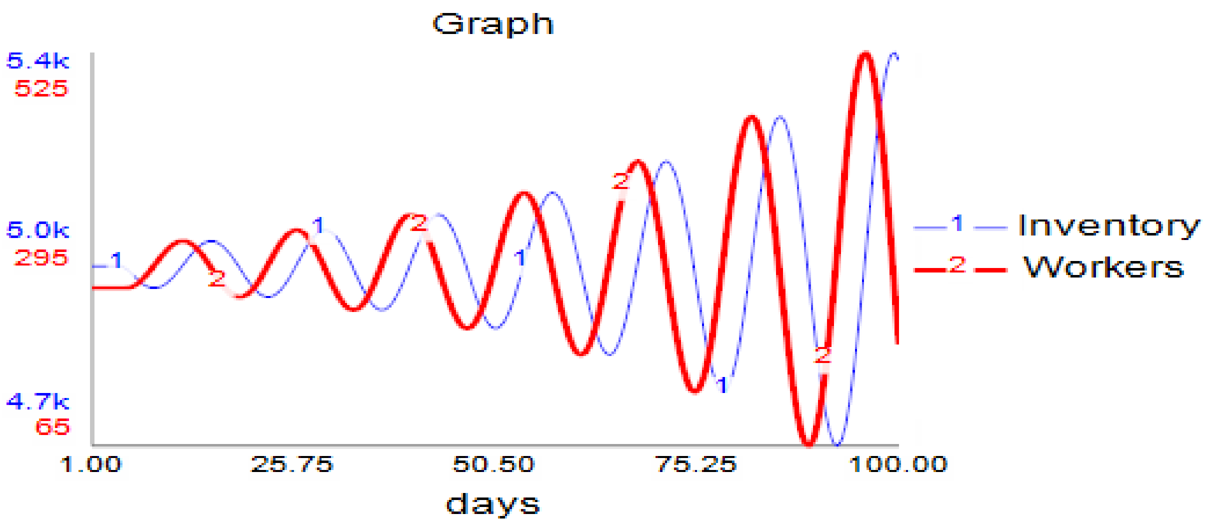
Policy Run 1 VALUING EMPLOYEES AS AN ASSET

In a labour-intensive firm, employees are the important dimension, many human based practices can be in placed to enhance the labour productivity and to improve the skill set of workers so that they become effective workers in a shortest possible time to make the products which are saleable in nature. Training whether it is soft skills or hard skills can be provided to workers that appear in the form of worker adjustment time or worker training time. The less time means workers are not properly trained and due to lacking skills can not produce more units. The impact of Worker Training Time (WAT) is a measure sensitive parameter. Our pre-simulation prediction was that if we reduce the worker training time using Worker training programme. The workers will be in position to contribute more raising the production level; consequently inventory discrepancy decrease and stock of inventory will build up. But the results are contrary to the pre-simulation prediction. Stock still has declining trend. No doubt, value of WAT = 1 days as compared to WAT = 2 days eliminates the information delay and brings the stability in system earlier. This policy is based on parametric change.



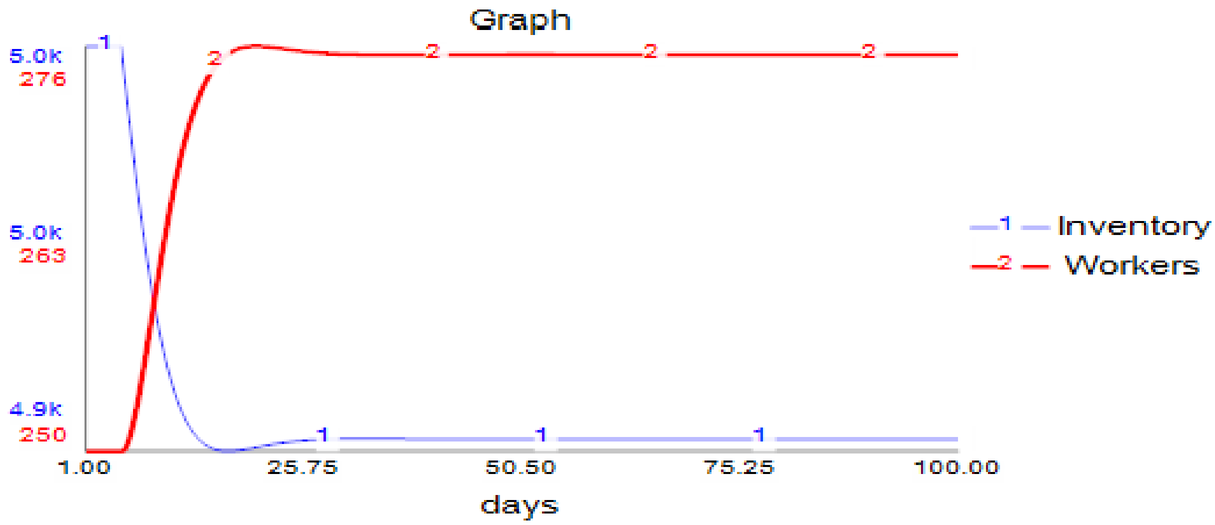
Policy Run 2 TECHNOLOGY DEPLOYMENT

It was another suggestion that we should introduce Information Technology (IT) based practices a either the management information system (MIS) or the enterprise resource planning (ERP) or technology deployment initiative in order to reduce inventory adjustment time (IAT). As soon as the discrepancy in inventory is observed, with the fastest means of communication real time information is immediately sent to administration team to hire the workers. The objective is to adjust the inventory discrepancy in the least time frame through faster information flow system. But simulation results tell the different story; value of IAT = 1 days as compared to 5 days increases oscillations and vanishes system's stability. This policy is based on parametric change.



Policy Run 3 CHANGING IN HIRING PROCESS

There is a need to change the hiring process of the workers. Desired workers were initially calculated on the basis of the inventory discrepancy but the true requirement of labour force must be calculated while comparing the new labour requirement with existing stock of workers. The net workers are the true workers who can enhance the marginal production increase which has a match with inventory discrepancy. This policy is based on structural change.



Conclusions. Policy experiments indicate that interactions among expected demand, workers and inventory are complex and dynamic in nature. It is hard to understand the factory dynamics intuitively. Here few assumptions like there is no shortage of raw material, expected demand is stepped up to disturb the steady state simplified the model. Even then pre-simulation expectations in parametric based policies are not generating the behaviour of the model that brings stability in workforce level and inventory. Structural based policy helps to achieve the desired results. This paper encourages top-line managers to implement system dynamics approach in decision-making process and design plausible policies to make the system better behaved, mere judgment and intuition may mislead the top line executives..

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