JOŠKO DVORNIK, D.Sc.
E-mail: josko@pfst.hr
ANTE MUNITIĆ, D.Sc.
E-mail: ante.munitic@pfst.hr
MIRKO BILIĆ, M.Sc.
E-mail: mirko.bilic@pfst.hr
University of Split, Faculty of Maritime Studies
Zrinsko-Frankopanska 38, HR-21000 Split,
Republic of Croatia

Invited Paper
Section: Education in Traffic and Transportation
Review
Accepted: Dec. 15, 2005
Approved: Feb. 21, 2006

SIMULATION MODELLING AND HEURISTICS OPTIMIZATION OF MATERIAL FLOW OF THE PORT CARGO SYSTEM

ABSTRACT

Simulation Modelling, together with System Dynamics and intensive use of modern digital computer, which means massive application, today very inexpensive and at the same time very powerful personal computers (PCs), is one of the most suitable and effective scientific ways for investigation of the dynamics behaviour of non-linear and complex: natural, technical and organization systems.

The methodology of System Dynamics (Prof dr. J. Forrester – MIT), e. g. a relatively new scientific discipline, in the former educational and designer practice showed its efficiency in practice as very suitable means for solving the problems of management, behaviour, sensibility, flexibility and sensibility of behaviour dynamics of different systems and processes.

The system-dynamics computer simulation methodology was used from 1991 to 2003 for modelling of dynamics behaviour of a large number of non-linear ship electrical, thermo-dynamical, hydraulic, mechanical and pneumatic systems. This methodology is used by students as the material for graduate theses, and for realization and publishing the results of scientific research work by the professors at High Maritime School and Maritime Faculty Split.

The aim of this paper is to show the efficiency of the application of the System Dynamics Simulation Modelling in investigation of behaviours dynamics, one of the Port-Transhipment systems presented with mental-verbal, structural and mathematical-computing modules, and it will simulate transhipment port working processes.

KEY WORDS

system dynamics, modelling, transhipment system, heuristic optimization, continuous and discrete simulation, port manager planner

1. INTRODUCTION

The System Dynamics Modelling is basically a special, i. e. "holistic" approach to the simulation of the dynamics behaviour of natural, technical and organization systems. Systems dynamics comprises qualitative and quantitative simulation modelling, and the concept of optimization of dynamic systems and processes is based on the so-called "heuristic" procedure. This means the method of manual and iterative procedure, which is automated with the help of fast digital computer, named "heuristic optimization" (trial and error!). This simulation model is only one of a large number of developed and educationally and practically used simulation models for education and training of young students – mariners, that use the so-called "white box" philosophy of investigating the complex systems, as distinguished from the "black box" approach! All simulation models developed in the last decade of the past century at the Maritime Faculty Split, Croatia, are a component of the scientific macro-project called: *Intelligent Computer Simulation of the Model of Marine Processes.*

2. SYSTEM DYNAMICS MODELLING OF THE PORT-TRANSHIPMENT SYSTEM

2.1. Qualitative Modelling of the Port-Transhipment System

a) Mental-verbal model of the Port-Transhipment System

Fundamentally, unloading of any kind of cargo can be divided into:

- ship arrival to the berthing position,
- unloading the cargo from the ship to the shore,
- transport of cargo from the shore to the wagons, trucks and warehouses.

Unloading/loading of the cargo in port is a complex dynamics process with two subsystems:
- Unloading/loading of the cargo in port (BUTUL),
- Surrounding environment (OS).

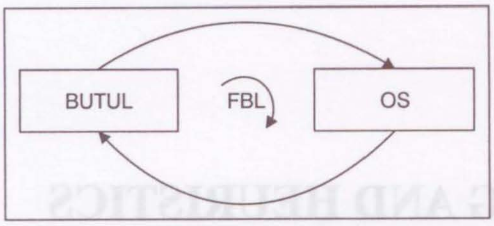

Figure 1 - Basic structural model of the Port-Transhipment System

Subsystem BUTUL has at least four sectors, i. e. subsections:
1. State of occupation of the berth;
2. Number of the cranes (on the ship and on the shore), which are objective at disposal;
3. Number of the fork-lift trucks, which are actually available;
4. Warehouses (number and the area that are actually available).

Subsystem OS has at least four sectors i. e. subsections:
1. Waiting ship (at berth or in arrival);
2. Engaged wagon capacities;
3. Engaged truck capacities;
4. Consignee (receiver) of the cargo.

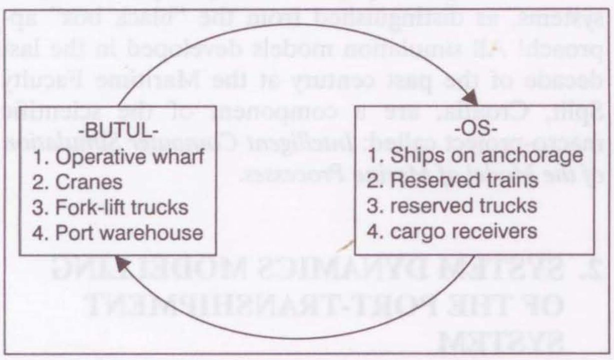

Figure 2 - Structural diagram of depending BUTUL and OS model of the Port Transhipment System

This example of PPL represents the "semi-indirect system of cargo reloading" with the preference to "maintaining the process of cargo unloading interrupted", because it is in the financial interest for the ship owner! In other words, if during the day (24h) the equipment that had been reserved in advance for loading and unloading of cargo (such as crane, fork-lift truck, railway vehicle, road vehicle and space in warehouse) become insufficient, the port-transport manager must give an order to stop the unloading of the ship. The unloading of the ship can start again when the new equipment i. e. available transport capacities are reserved (in this case railway and road vehicle).

b) Structural model of Port Transhipment System (PPL):

In order to present a complete structural model of PPL it is necessary to present the so-called "rudimentary structural model of material and information flow" with the addition of the given mental-verbal model (Figure 3.).

The "Generator of ship arrival" is fictitious exogenous source of ship cargo (new arriving ship), which can be realized only if the state of occupation of the berth is zero i. e. completely free. It is necessary to point out that most of the ports have more than one berth, while in this elementary example the number of the berths =1. "The speed of unloading the ship" depends on the "state of busyness of the berth" and on number of i. e. the "capacity of the crane". "The speed of transporting the cargo" from the point of unloading (Berth 1) to the swing-gate for the loading in wagons, trucks or in port warehouse depends on the "speed of unloading the cargo" and on the "number of engaged fork-lift trucks".

Material flow of the unloaded cargo in port (local transport in port) is realized from the point where the cargo is unloaded i. e. berth 1 to the loading platforms of the reserved wagons or road vehicles, or port warehouse (depending on whether there is free space in it).

The unloaded cargo is directed to railway platform, i. e. cargo is loaded onto available railway capacities that have been reserved in advance (24h).

If the railway capacities are fully loaded before the end of the first day of unloading, then the port-transport manager gives an order to start loading onto road vehicles that have been reserved in advance.

If within the limited time of one day, i. e. 24 hours of continual unloading of ship cargo all available road vehicle are used (daily reserved contingent) and new contingent of railway wagons does not follow, then port-transport manager gives an order to start temporary storage of unloaded ship cargo until there is free space in the warehouse.

In case we do not have the planned (daily reserved in-advance) loading at disposal i. e. railway, road and storage capacities, the port manager gives an "expensive" order, i. e. to stop the unloading of the ship cargo until the arrival of the new railway or road transport contingent which is daily reserved in advance.

- In the event that the new available transport capacities (wagons and trucks) arrive on time it is possible to carry on with the unloading of the ship and loading into the reserved transport in full accordance with the described expert logical decision of port manager.

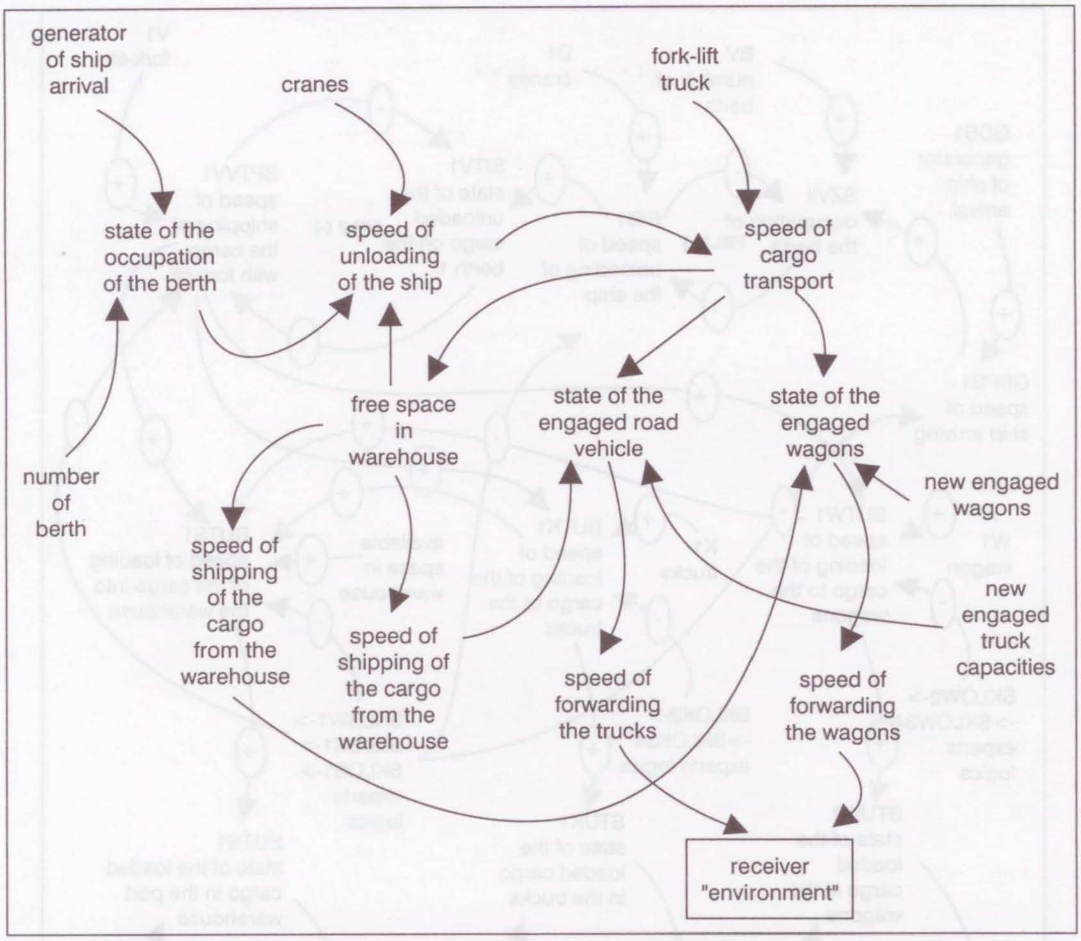

Figure 3 - Material and information flows of the PTSS and environment

Based on the earlier described mental-verbal system dynamics model it is possible to determine the "system dynamics structural model" PPL (Figure 3).

The "Expert-logical" material flow of unloaded cargo is divided into three available and possible loadings i. e. placing of the cargo that has been brought by fork-lift trucks into: 1. the daily reserved railway wagon capacities, and if they are not sufficient, then to load the already unloaded cargo on berth 1 (24-hour working day) onto: 2. in-advance reserved daily trucks capacities, and if they are also insufficient for placing the ship cargo and can cause interruption of continued process of unloading and shipping of the cargo i. e. the most expensive solution, which, if possible, should be avoided, then: 3. into free storage space.

In accordance with the system dynamics between these three possible flows of unloaded cargo there is large degree of analogy, and it is possible to determinate the structural simulation model (flow diagram) of unloading the cargo onto railway wagons. (Figure 4)

Five reflexive circles dominate in the System Dynamics structural simulation model of the PPL: **(FBL-a): FBL1(-); FBL2(-); FBL3(-); FBL4(-) and FBL5(-):**

FBL1(-): SZVI1(occupation of the berth)(+) → (+)BIB1(speed of unloading of the ship)(+) → (-)SZVI1(occupation of the berth).

FBL2(-): SITV1(state of the unloaded cargo on the berth)(+) →(+)BPTVV1(speed of shipping of the cargo with work-lift)(+) →(-)SITV1(state of the unloaded cargo on berth 1).

FBL3(-): STUW1(state of the loaded cargo on the wagons) (+) → (+) FBOW1 (fictitious speed of forwarding the wagons)(+) →(-)STUW1(state of the loaded cargo on the wagons).

FBL4(-): STUK1(speed of loading of the cargo to the trucks)(+) → (+)FBOK1(fictitious speed of forwarding the trucks)(+)→(-)STUK1(speed of loading of the cargo to the trucks).

FBL5(-): SUTS1(state of the unloaded cargo in the port Warehouse) (+)→ (+)FBOS1 (fictitious speed of emptying the warehouse) (+)→(-) SUTS1(state of the unloaded cargo in the port Warehouse).

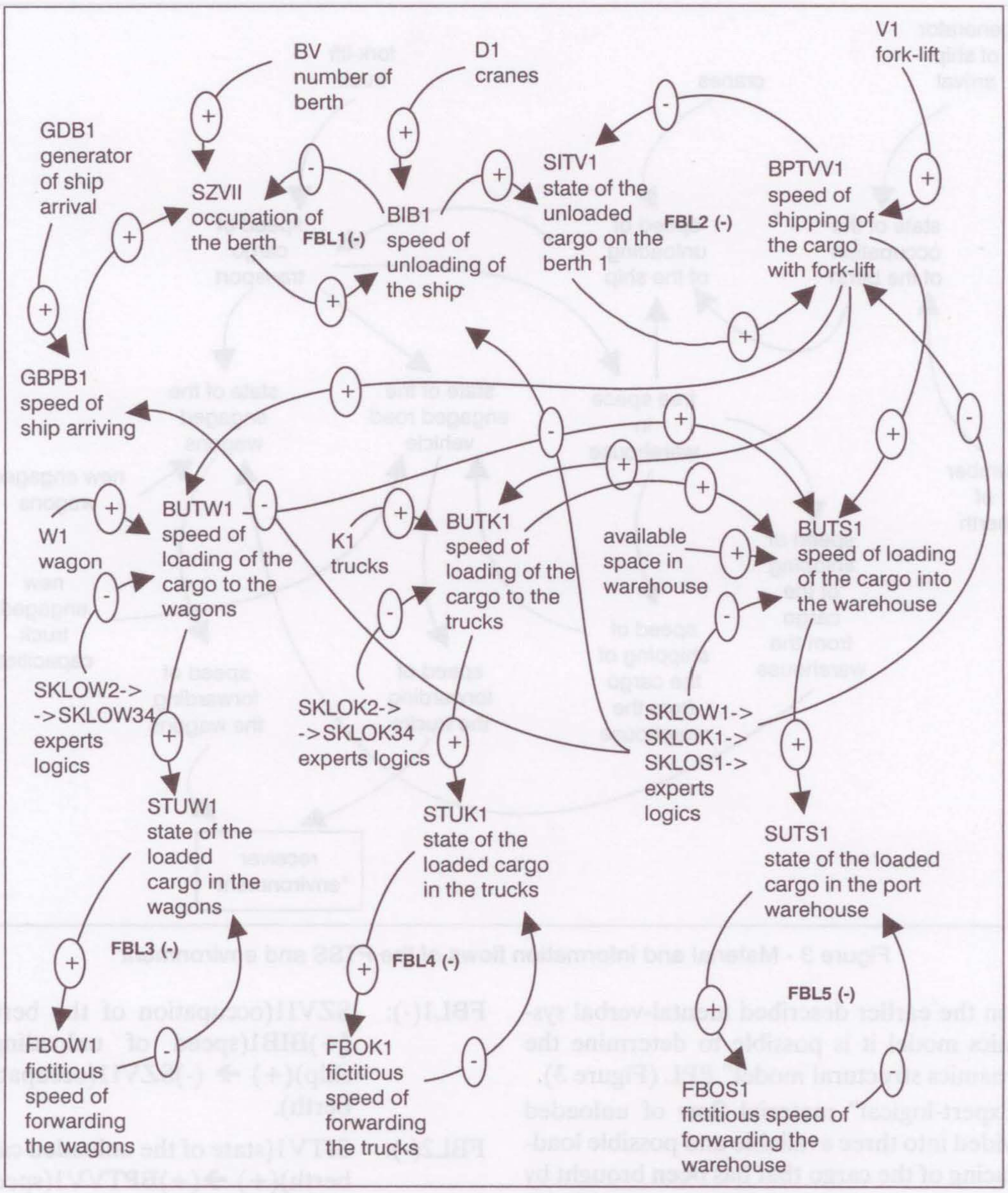

Figure 4 - System Dynamics structural simulation model of the PPL

c) Structural flow diagram in POWERSIM symbolic:

Based on determined mental-verbal and structural model of the PPL-a, and according to the POWERSIM program graphic symbolic, it is possible to determine the system-dynamics model, i. e. flow diagram of the PPL-a, i. e. its subsectors which are interconnected to one another and form a whole.

Figure 5 shows the complete SD diagram of flow diagrams of model of the PPL-a.

Where:

GDB1= generator of ship arrival,

BPB1= speed of putting the ship to shore,

SZV1= state of occupation of the berth,

BIB1= speed of unloading the ship,

D1= number of cranes,

SITV1= state of the unloaded cargo on berth 1,

BPTVV1= speed of shipping of the cargo with fork-lift from berth1 to the platforms for loading on the wagons, trucks or warehouse,

BPTVV11= speed of shipping the cargo with fork-lift from berth 1 in case that SITV1 is multiple of the number of the fork-lift trucks,

V1=number of fork-lift trucks,

SKLOS1= conditional logical function that limits the filled warehouse,

SUTS1= state of the loaded cargo at the warehouse,

BPTSV1= speed of shipping of the cargo to the warehouse,

BUTW1= speed of loading of cargo on the wagons,

SKLOWWW= conditional complex logical function,

VUTW1= time needed for loading the cargo onto the wagons,

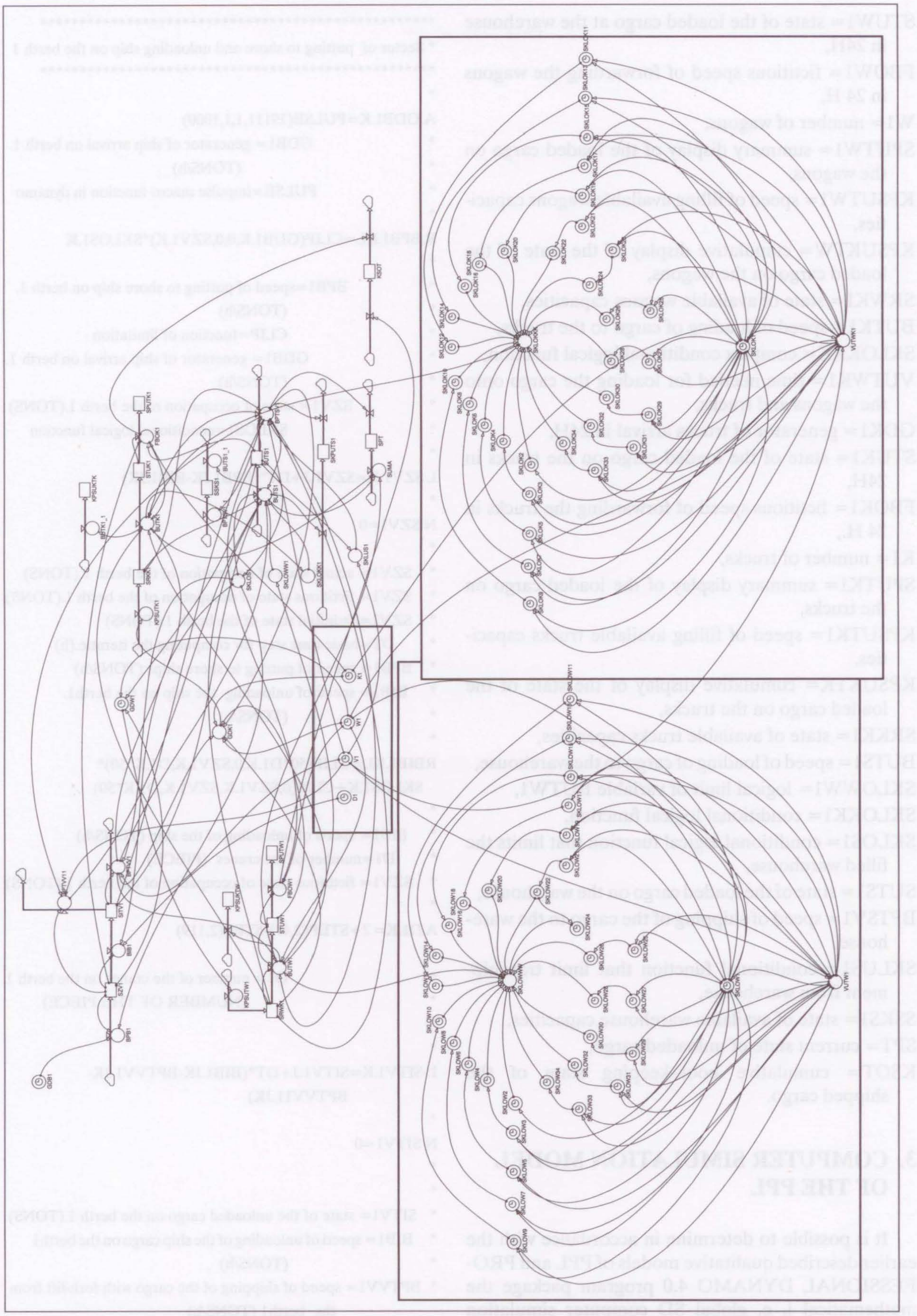

Figure 5 - Complete SD diagram of flow diagrams of simulation model of the PPL (POWERSIM)

STUW1= state of the loaded cargo at the warehouse in 24H,

FBOW1= fictitious speed of forwarding the wagons in 24 H,

W1= number of wagons,

SPUTW1= summary display of the loaded cargo on the wagons,

KPSUTW1= speed of filling available wagons capacities,

KPSUKTW= cumulative display of the state of the loaded cargo on the wagons,

SRWK1= state of available wagons capacities,

BUTK1= speed of loading of cargo to the trucks,

SKLOKKK= complex conditional logical function,

VUTWK1= time needed for loading the cargo onto the wagons and trucks,

GDK1= generator of trucks arrival in 24H,

STUK1= state of the loaded cargo on the trucks in 24H,

FBOK1= fictitious speed of forwarding the trucks in 24 H.,

K1= number of trucks,

SPUTK1= summary display of the loaded cargo on the trucks,

KPSUTK1= speed of filling available trucks capacities,

KPSUKTK= cumulative display of the state of the loaded cargo on the trucks,

SRKK1= state of available trucks capacities,

BUTS1= speed of loading of cargo to the warehouse,

SKLOWW1= logical limit of variable BUTW1,

SKLOKK1= conditional logical function,

SKLOS1= conditional logical function that limits the filled warehouse,

SUTS1= state of the loaded cargo on the warehouse,

BPTSV1= speed of shipping of the cargo to the warehouse,

SKLUS1= conditional function that limit transhipment from warehouse,

SSKS1= state of available warehouse capacities,

SPT= current state of unloaded cargo,

KSOT= cumulative book-keeping state of the shipped cargo.

3. COMPUTER SIMULATION MODEL OF THE PPL

It is possible to determine in accordance with the earlier described qualitative models of PPL and PROFESSIONAL DYNAMO 4.0 program package the mathematical i. e. global SD computer simulation model of PPL:

```
**************************************************
* Sector of putting to shore and unloading ship on the berth 1
**************************************************
*
A GDB1.K=PULSE(19111,1,1,1000)
*          GDB1= generator of ship arrival on berth 1.
*                (TONS/h)
*          PULSE=impulse macro function in dynamo
*
R BPB1.KL=CLIP(GDB1.K,0,0,SZV1.K)*SKLOS1.K
*
*          BPB1=speed of putting to shore ship on berth 1.
*                (TONS/h)
*                CLIP=function of limitation
*          GDB1= generator of ship arrival on berth 1.
*                (TONS/h)
*          SZV1= state of occupation of the berth 1.(TONS)
*                SKLOS1=conditional logical function
*
L SZV1.K=SZV1.J+DT*(BPB1.JK-BIB1.JK)
*
N SZV1=0
*
*  SZV1= actual state of occupation of the berth 1.(TONS)
*  SZV1= fictitious state of occupation of the berth 1.(TONS)
*  SZV1=0=initial state of the berth 1.(TONS)
*    DT=basic time step for computing the iteratie.(h)
*  BPB1= speed of putting to shore ships (TONS/h)
*  BIB1= speed of unloading the ship on the berth1.
*                (TONS/h)
*
RBIB1.KL=CLIP(50*D1.K,0,SZV1.K,D1.K*50)*
  SKLOS1.K+CLIP(0,SZV1.K,SZV1.K,D1.K*50)
*
*  BIB1= speed of unloading of the ship (TONS/h)
*    D1=number of the cranes (PIECE)
*  SZV1= fictitious state of occupation of the berth 1.(TONS)
*
A D1.K= 2+STEP(2,47)-STEP(2,119)
*
*                D1= number of the cranes on the berth 1.
*                    (NUMBER OF THE PIECE)
*
*
L SITV1.K=SITV1.J+DT*(BIB1.JK-BPTVV1.JK-
          BPTVV11.JK)
*
N SITV1=0
*
*
*  SITV1= state of the unloaded cargo on the berth 1.(TONS)
*  BIB1= speed of unloading of the ship cargo on the berth1
*                (TONS/h)
*  BPTVV1= speed of shipping of the cargo with fork-lift from
*           the berth1 (TONS/h)
*
```

```
R BPTVV1.KL=CLIP(50*V1.K,0,SITV1.K,1E-
        30)*SKLOS1.K
*
R BPTVV11.KL=CLIP(0,SZV1.K,SZV1.K,
        V1.K*50)*CLIP(0,1,BPTSV1.KL,1E-30)
*
*   BPTVV1= speed of shipping of the cargo with fork-lift
        from the berth1 (TONS/h)
*   V1=number of the fork-lift (PIECE)
*   SITV1= state of the unloaded cargo on the berth 1(TONS)
* SKLOS1= conditional logical function
A V1.K= 2+STEP(2,47)-STEP(2,119)
*
*              V1= number of the fork-lift (PIECE)
* ***************************************************
SAVE GDB1,BPB1,SZV1,D1,BIB1,SITV1
SAVE BPTVV1,V1,SITV1,BPTVV11
* ***************************************************
* Sector of the material flow of loading the cargo on the wagons:
* ***************************************************
*
R BUTW1.KL=CLIP(0,BPTVV1.KL+BPTSV1.KL,
  STUW1.K,25*W1.K)*SKLOWWW.K+CLIP(BPTVV1.KL
  +BPTSV1.KL,0,STUW1.K,25*W1.K)*
*        CLIP(1,0,SRWK1.K,1E-30)
*
*   BUTW1= speed of laoding of cargo on the wagons from
        the berth 1. (TONS/h)
* BPTVV1= speed of shipping of the cargo with fork-lift from
        the berth 1.
*        (TONS/h)
*   STUW1= state of the loaded cargo on the wagons within
        24 (TONS)
*   SKLOWWW= conditional complex logical function
*   W1= number of the wagons (PIECE)
*
A SKLOWWW.K=SKLOW2.K*SKLOW4.K*
 SKLOW6.K*SKLOW8.K*SKLOW10.K*SKLOW12.K*
 SKLOW14.K*SKLOW16.K*SKLOW18.K*SKLOW20.K*
 SKLOW22.K*SKLOW24.K*SKLOW26.K*SKLOW28.K*
 SKLOW30.K*SKLOW32.K*SKLOW34.K
*
*   SKLOWWW= conditional complex logical function
* SKLOW1 ....SKLOW34= conditional logical functions
*
* ***************************************************
Subsector of logical management of loading the cargo in the wagons:
* ***************************************************
*
A VUTW1.K=((25*W1.K)/(50*V1.K))
*
*   VUTW1= VUTW1
*        W1= number of the wagons (PIECE)
*        V1= number of the fork-lifts (PIECE)
*
A SKLOW1.K=CLIP(1,0,3+VUTW1.K,TIME.K)
*
A SKLOW2.K=CLIP(1,SKLOW1.K,TIME.K,24)
*
A SKLOW3.K=CLIP(1,SKLOW1.K,24+VUTW1.K,TIME.K)
*
A SKLOW4.K=CLIP(1,SKLOW3.K,TIME.K,48)
*
A SKLOW5.K=CLIP(1,SKLOW1.K,48+VUTW1.K,TIME.K)
*
A SKLOW6.K=CLIP(1,SKLOW5.K,TIME.K,72)
*
A SKLOW7.K=CLIP(1,SKLOW1.K,72+VUTW1.K,TIME.K)
*
A SKLOW8.K=CLIP(1,SKLOW7.K,TIME.K,96)
*
A SKLOW9.K=CLIP(1,SKLOW1.K,96+VUTW1.K,TIME.K)
*
A SKLOW10.K=CLIP(1,SKLOW9.K,TIME.K,120)
*
A SKLOW11.K=CLIP(1,SKLOW1.K,120+
  VUTW1.K,TIME.K)
*
A SKLOW12.K=CLIP(1,SKLOW11.K,TIME.K,144)
*
A SKLOW13.K=CLIP(1,SKLOW1.K,144+
  VUTW1.K,TIME.K)
*
A SKLOW14.K=CLIP(1,SKLOW13.K,TIME.K,168)
*
A SKLOW15.K=CLIP(1,SKLOW1.K,168+
  VUTW1.K,TIME.K)
*
A SKLOW16.K=CLIP(1,SKLOW15.K,TIME.K,192)
*
A SKLOW17.K=CLIP(1,SKLOW1.K,192+
  VUTW1.K,TIME.K)
*
A SKLOW18.K=CLIP(1,SKLOW17.K,TIME.K,216)
*
A SKLOW19.K=CLIP(1,SKLOW1.K,216+
  VUTW1.K,TIME.K)
*
A SKLOW20.K=CLIP(1,SKLOW19.K,TIME.K,240)
*
A SKLOW21.K=CLIP(1,SKLOW1.K,240+
  VUTW1.K,TIME.K)
*
A SKLOW22.K=CLIP(1,SKLOW21.K,TIME.K,264)
*
A SKLOW23.K=CLIP(1,SKLOW1.K,264+
  VUTW1.K,TIME.K)
*
A SKLOW24.K=CLIP(1,SKLOW22.K,TIME.K,288)
```

```
*
A SKLOW25.K=CLIP(1,SKLOW1.K,288+
    VUTW1.K,TIME.K)
*
A SKLOW26.K=CLIP(1,SKLOW25.K,TIME.K,312)
*
A SKLOW27.K=CLIP(1,SKLOW1.K,312+
    VUTW1.K,TIME.K)
*
A SKLOW28.K=CLIP(1,SKLOW27.K,TIME.K,336)
*
A SKLOW29.K=CLIP(1,SKLOW1.K,336+
    VUTW1.K,TIME.K)
*
A SKLOW30.K=CLIP(1,SKLOW29.K,TIME.K,360)
*
A SKLOW31.K=CLIP(1,SKLOW1.K,360+
    VUTW1.K,TIME.K)
*
A SKLOW32.K=CLIP(1,SKLOW31.K,TIME.K,384)
*
A SKLOW33.K=CLIP(1,SKLOW1.K,384+
    VUTW1.K,TIME.K)
*
A SKLOW34.K=CLIP(1,SKLOW33.K,TIME.K,408)
*.....................................................................
*
*A GDW1.K=PULSE(25*W1.K,1,0,2400)
+PULSE(25*W1.K,1,23,2400)+PULSE(25*W1.K,1,47,2400)+P
ULSE(25*W1.K,1,71,2400)+PULSE(25*W1.K,1,95,2400)
+PULSE(25*W1.K,1,119,2400)+PULSE(25*W1.K,1,143,240
 0)+PULSE(25*W1.K,1,167,2400)+ PULSE(25*W1.K,1,
191,2400)+PULSE(25*W1.K,1,215,2400)+PULSE(25*W1.K,1,23
9,2400)+PULSE(25*W1.K,1,263,2400)+ PULSE(25*
W1.K,1,287,2400)+PULSE(25*W1.K,1,311,2400)+PULSE(25*W
1.K,1,335,2400)+PULSE(25*W1.K,1,359,2400)+PULSE
(25*W1.K,1,383,2400)+PULSE(25*W1.K,1,407,2400))*
CLIP(1,0,SZV1.K+SUTS1.K,1E-30)
*
*        GDW1= generator of wagon arrival in 24H(TONS)
*        W1= number of the wagons (PIECE)
*
*
L STUW1.K=STUW1.J+DT*(BUTW1.JK-FBOW1.JK)

N STUW1=0
*
*   STUW1= state of the loaded cargo on the wagons in 24H
*               (TONS)
*   BUTW1= speed of loading of the cargo on the wagons on
*          berth1. (TONS/h)
* FBOW1=fictitious speed of forwarding the wagons in 24 H.
*               (TONS/h)
*  STUW1=0= initial state of the loaded cargo on the wagons.
*               (TONS)
*
R FBOW1.KL=CLIP(STUW1.K,0,STUW1.K,25*W1.K)+
 CLIP(0,STUW1.K,SZV1.K+SUTS1.K,1E-30)
*
*
*
* FBOW1= fictitious speed of forwarding the wagons in 24H
*               (TONS)
* STUW1= state of the loaded cargo on the wagons in24H
*               (TONS)
*        W1= number of the wagons (PIECE)
*
A W1.K= 56+STEP(40,71)-STEP(40,119)

*
*               W1= number of the wagons (PIECE)
*
L SPUTW1.K=SPUTW1.J+DT*FBOW1.JK
*
N SPUTW1=0

* SPUTW1=summary display of the loaded cargo on the
*          wagons     (TONS)
* FBOW1= fictitious speed of forwarding the wagons in 24H
*               (TONS)
* SPUTW1=0= initial state of the loaded cargo on the wagons.
*               (TONS)
*

R KPSUTW1.KL=GDW1.K
*
L KPSUKTW.K=KPSUKTW.J+DT*BUTW1.JK
*
N KPSUKTW=0

L SRWK1.K=SRWK1.J+DT*(KPSUTW1.JK-BUTW1.JK)
*
N SRWK1=0
*
SAVE BUTW1,GDW1,STUW1,FBOW1,W1,SPUTW1
*
SAVE KPSUKTW,SRWK1,KPSUTW1
* ***********************************************
* ***********************************************
* Sector of the material flow of loading the cargo onto the trucks:
* ***********************************************
*
R BUTK1.KL=CLIP(0,BPTVV1.KL+
BPTSV1.KL,BUTW1.KL,1E30)*SKLOKKK.K*^
CLIP(0,1,FBOK1.KL,1E-30)*CLIP(0,1,SRWK1.K,1E-30)
*
*    BUTK1= speed of loading of cargo to the trucks from the
*          berth 1.  (TONS/h)
*  BPT= speed of shipping of the cargo with fork-lift from the
*          berth 1.  (TONS/h)
*    BUTW1= speed of loading of cargo on the wagons from
*          the berth 1.  (TONS/h)
```

```
*    SKLOKKK= conditional complex logical function
*
A SKLOKKK.K=SKLOK2.K*SKLOK4.K*
        SKLOK6.K*SKLOK8.K*SKLOK10.K*SKLOK12.K* ^
SKLOK14.K*SKLOK16.K*SKLOK18.K*SKLOK20.K*
SKLOK22.K*SKLOK24.K* SKLOK26.K*SKLOK28.K*
SKLOK30.K*SKLOK32.K*SKLOK34.K
*
*    SKLOKKK= conditional complex logical function
*    SKLOK1 ....SKLOK34= conditional logical functions
*
* Subsector of logical management of loading the cargo on the
trucks:
*
*
A VUTWK1.K=(25*W1.K+20*K1.K)/(50*V1.K)
*
* VUTWK1=time needed for loading of the cargo on the
        wagon and trucks
*    W1= number of the wagons (PIECE)
*    K1 = number of the trucks (PIECE)
*    V1= number of the fork-lifts (PIECE)
*
*
A SKLOK1.K=CLIP(1,0,3+VUTWK1.K,TIME.K)
*
A SKLOK2.K=CLIP(1,SKLOK1.K,TIME.K,24)
*
A SKLOK3.K=CLIP(1,SKLOK1.K,24+
    VUTWK1.K,TIME.K)
*
A SKLOK4.K=CLIP(1,SKLOK3.K,TIME.K,48)
*
A SKLOK5.K=CLIP(1,SKLOK1.K,48+
    VUTWK1.K,TIME.K)
*
A SKLOK6.K=CLIP(1,SKLOK5.K,TIME.K,72)
*
A SKLOK7.K=CLIP(1,SKLOK1.K,72+
    VUTWK1.K,TIME.K)
*
A SKLOK8.K=CLIP(1,SKLOK7.K,TIME.K,96)
*
A SKLOK9.K=CLIP(1,SKLOK1.K,96+
    VUTWK1.K,TIME.K)
*
A SKLOK10.K=CLIP(1,SKLOK9.K,TIME.K,120)
*
A SKLOK11.K=CLIP(1,SKLOK1.K,120+
    VUTWK1.K,TIME.K)
*
A SKLOK12.K=CLIP(1,SKLOK11.K,TIME.K,144)
*
A SKLOK13.K=CLIP(1,SKLOK1.K,144+
    VUTWK1.K,TIME.K)
*
A SKLOK14.K=CLIP(1,SKLOK13.K,TIME.K,168)
*
A SKLOK15.K=CLIP(1,SKLOK1.K,168+
    VUTWK1.K,TIME.K)
*
A SKLOK16.K=CLIP(1,SKLOK15.K,TIME.K,192)
*
A SKLOK17.K=CLIP(1,SKLOK1.K,192+
    VUTWK1.K,TIME.K)
*
A SKLOK18.K=CLIP(1,SKLOK17.K,TIME.K,216)
*
A SKLOK19.K=CLIP(1,SKLOK1.K,216+
    VUTWK1.K,TIME.K)
*
A SKLOK20.K=CLIP(1,SKLOK19.K,TIME.K,240)
*
A SKLOK21.K=CLIP(1,SKLOK1.K,240+
    VUTWK1.K,TIME.K)
*
A SKLOK22.K=CLIP(1,SKLOK21.K,TIME.K,264)
*
A SKLOK23.K=CLIP(1,SKLOK1.K,264+
    VUTWK1.K,TIME.K)
*
A SKLOK24.K=CLIP(1,SKLOK23.K,TIME.K,288)
*
A SKLOK25.K=CLIP(1,SKLOK1.K,288+
    VUTWK1.K,TIME.K)
*
A SKLOK26.K=CLIP(1,SKLOK25.K,TIME.K,312)
*
A SKLOK27.K=CLIP(1,SKLOK1.K,312+
    VUTWK1.K,TIME.K)
*
A SKLOK28.K=CLIP(1,SKLOK27.K,TIME.K,336)
*
A SKLOK29.K=CLIP(1,SKLOK1.K,336+
    VUTWK1.K,TIME.K)
*
A SKLOK30.K=CLIP(1,SKLOK29.K,TIME.K,360)
*
A SKLOK31.K=CLIP(1,SKLOK1.K,360+
    VUTWK1.K,TIME.K)
*
A SKLOK32.K=CLIP(1,SKLOK31.K,TIME.K,384)
*
A SKLOK33.K=CLIP(1,SKLOK1.K,384+
    VUTWK1.K,TIME.K)
*
A SKLOK34.K=CLIP(1,SKLOK33.K,TIME.K,408)
*
* ------------------------------------------------
A GDK1.K=CLIP(20*K1.K,0,STUW1.K,
(25*W1.K-BPTVV1.KL-BPTSV1.KL))* ^
CLIP(0,1,STUW1.K,25*W1.K)*CLIP(0,1,SRWK1.K-
```

```
BPTVV1.KL BPTSV1.KL,1E-30)
*
*      GDK1= generator of trucks arrival in 24H(TONS)
*                   K1= number of the trucks (PIECE)
*
L STUK1.K=STUK1.J+DT*(BUTK1.JK-FBOK1.JK)
*
N STUK1=0
* STUK1=state of the loaded cargo on the trucks in24H
           (TONS)
* BUTK1= speed of loading of cargo on the trucks (TONS/h)
* FBOK1= fictitious speed of forwarding the trucks in 24 H.
*              (TONS)
* STUK1=0= initial state of the loaded cargo on the trucks
*              (TONS)
*
R FBOK1.KL=CLIP(STUK1.K,0,STUK1.K,20*K1.K)+
*            CLIP(0,STUK1.K,SZV1.K+SUTS1.K, 1E-30)
*
*   FBOK1= fictitious speed of forwarding the trucks in 24 H.
*              (TONS)
*    STUK1=0= initial state of the loaded cargo on the trucks
*              (TONS)
*         K1= number of trucks (PIECE)
*
A K1.K= 20+STEP(10,47)-STEP(10,95)

*
*              K1= number of trucks (PIECE)
*
L SPUTK1.K=SPUTK1.J+DT*FBOK1.JK
*
N SPUTK1=0
*
*      SPUTK1= summary display of the loaded cargo on the
             trucks (TONS)
*     FBOK1= fictitious speed of forwarding the trucks in 24
             H.(TONS)
* SPUTK1=0= initial state of the loaded cargo on the trucks
             (TONS)
*
R KPSUTK1.KL=GDK1.K
*
L KPSUKTK.K=KPSUKTK.J+DT*BUTK1.JK
*
N KPSUKTK=0
*
L SRKK1.K=SRKK1.J+DT*(KPSUTK1.JK-BUTK1.JK)
*
N SRKK1=0
*
*
SAVE BUTK1,GDK1,STUK1,FBOK1,K1,SPUTK1
*
SAVE KPSUTK1,KPSUKTK,SRKK1
*
```

```
* **************************************************
* Sector of the material flow of transhipment of the cargo on to the
warehouse:
*
R BUTS1.KL=(BPTVV1.KL+BPTSV1.KL)*
        SKLOWW1.K*SKLOKK1.K*SKLOS1.K*CLIP(0,1,
SRWK1.K,1E-30)*CLIP(0,1,SRKK1.K,1E-30)*
CLIP(1,0,SITV1.K,1E-30)+BPTVV11.KL
*
*     BUTS1= speed of loading of cargo to the warehouse
               (TONS/ h)
* BPTVV1= speed of shipping of the cargo with fork-lift
               from the berth1 (TONS/h)
*      SKLOWW1= conditional complex logical function
*        SKLOKK1= conditional complex logical function
*        SKLOS1= conditional complex logical function
*
A SKLOWW1.K=CLIP(0,1,BUTW1.KL,1E-30)
*
*      SKLOWW1= limit of the variable BUTW1 (B.D.)
*    BUTW1= speed of loading of cargo on the wagons from
             the berth 1 (TONS/ h)
*     SKLOWW1= conditional complex logical function
*
A SKLOKK1.K=CLIP(0,1,BUTK1.KL,1E-30)
*
*     SKLOKK1= conditional complex logical function
* BUTK1= speed of loading of cargo on the trucks (TONS/ h)
*
A SKLOS1.K=CLIP(0,1,SUTS1.K,54000)
*
*               SKLOS1= conditional complex logical function
* SUTS1= state of the loaded cargo on the warehouse (TONS)
*              54000= capacity of the warehouse
*
L SUTS1.K=SUTS1.J+DT*(BUTS1.JK-BPTSV1.JK)
*
N SUTS1=0
*
* SUTS1= state of the loaded cargo on the warehouse (TONS)
* BUTS1= speed of loading of cargo to the warehouse
               (TONS/ h)
* SUTS1= 0= initial state of the loaded cargo to the
               warehouse (TONS)
*
R BPTSV1.KL=CLIP(0,50*V1.K, SITV1.K,1E-30)*
SKLUS1.K*CLIP(1,0,SRWK1.K+SRKK1.K,
1E-30)+CLIP(0,SUTS1.K,SUTS1.K,50*V1.K)*
CLIP(1,0,SRWK1.K+SRKK1.K,1E-30)
*
A SKLUS1.K=CLIP(1,0,SUTS1.K,50*V1.K)
*
L SKPUTS1.K=SKPUTS1.J+DT*(BUTS1.JK-BPTSV1.JK)
*
N SKPUTS1=0
*
```

```
L SSKS1.K=SSKS1.J+DT*(BPTSV1.JK-BUTS1.JK)
*
N SSKS1=54000
*
*  SPT=current state of unload cargo:
*
L SPT.K=SPT.J+DT*(BUTW1.JK+BUTK1.JK+BUTS1.JK-
        BPTSV1.JK)
*
N SPT=0
*
*  KSUTWK= state of the shipped cargo on the wagons and
           trucks:
*
L KSOT.K=KSOT.J+DT*(FBOW1.JK+FBOK1.JK)
*
N KSOT=0
* **************************************************
*
SAVE BUTS1,SUTS1,SPT,SKPUTS1,SSKS1
*
SAVE BPTSV1,SKLUS1,KSOT
* ...................................
*
SPEC DT=1,LENGTH=397,SAVPER=1
* **************************************************
```

3.1. Scenario of the simulation of PPL

This model includes putting to shore and unloading of the ship at berth, transhipment of cargo onto the wagons with subsection of logical management built in it, transhipment of cargo onto trucks also with subsection of logical management, an at the end, transhipment of cargo to the warehouse.

In this paper, due to its largeness, we will present only the zero scenario with initial conditions:

- unloading of the ship has been started in time T=0,
- Transhipment of cargo with cranes, and the number of cranes are D1= 2+STEP(2,47)-STEP (2,119), i. e. the capacities of the cranes are 50*D1
- Transhipment of cargo onto the fork-lift, and the number of fork-lift trucks is V1= 2+STEP(2,47)-STEP(2,119), i. e. the capacities of the cranes are 50*V1
- Transhipment of the cargo with fork-lift truck from the berth to the gate and transhipment onto the wagons, and the number of wagons are W1= 56+STEP(40,71)-STEP(40,119),
- transport of cargo onto trucks, and the number of trucks are K1= 20+STEP(10,47)-STEP(10,95),
- transport of the cargo in the warehouse, and capacities of the warehouse are 54000.

3.2. System dynamics simulation modelling results

Graphic results of simulation:

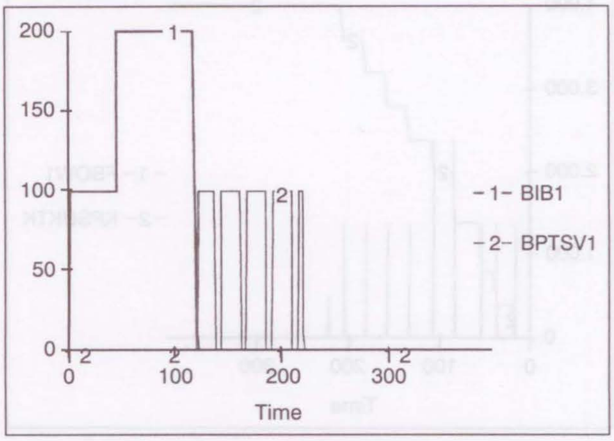

Figure 6 - Speed of unloading ship-BIB1, speed of shipping cargo to warehouse-BPTSV1

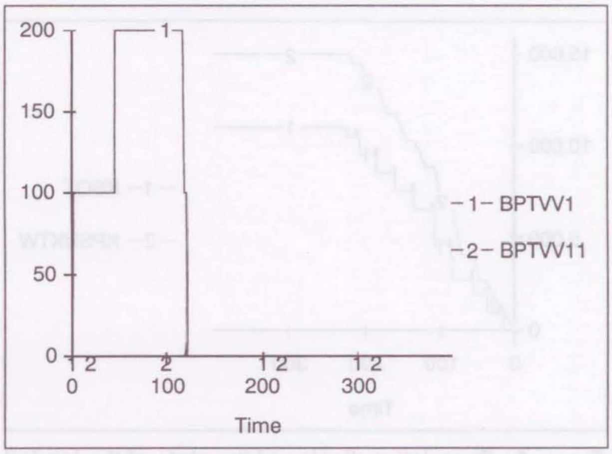

Figure 7 - Speed of shipping cargo with fork-lift from berth1 to the platforms for loading onto wagons, trucks or warehouse-BPTVV1, Speed of shipping cargo with fork-lift from berth 1 in the case that SITV1 is multiple of the number of the fork-lift-BPTVV11

Based on the presented simulation dynamics of behaviour of model in complex scenario it is possible to conclude as follows:

- It is possible to simulate the daily speed of unloading the ship and shipping the cargo from shore using STEP function; also, it is possible to simulate the daily need for trucks and wagons, and in that way avoid the necessary waiting of the new trucks and wagons and also to avoid stoppage of unloading the ship or shipping the cargo from the port warehouse.
- Also, the application of STEP function enables the control of all relevant data, daily and current data, following of unloading and shipping of the cargo, the state of the cargo at the port warehouse, available capacities in port warehouse, etc.

- Based on the obtained results it is possible to analyze the state of the system at any desired moment in time.

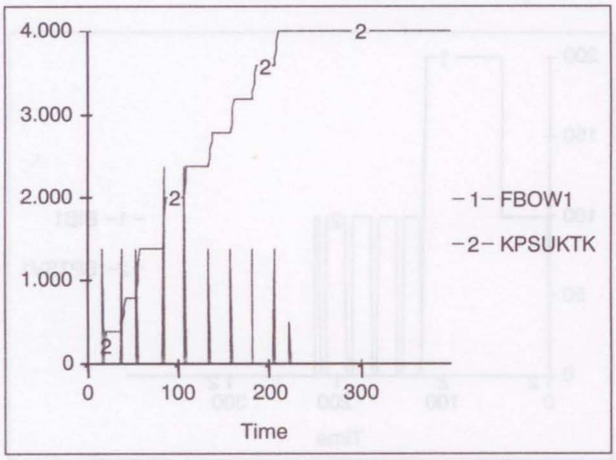

Figure 8 - Fictitious speed of forwarding the wagons in 24 H-FBOW1, Cumulative display of the state of the loaded cargo on the trucks-KPSUKTK

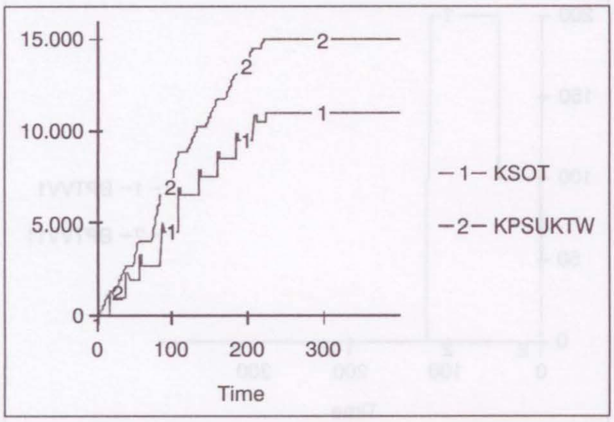

Figure 9 - Cumulative display of the state of the loaded cargo on the wagons-KPSUKTW, Cumulative book-keeping state of the shipped cargo-KSOT

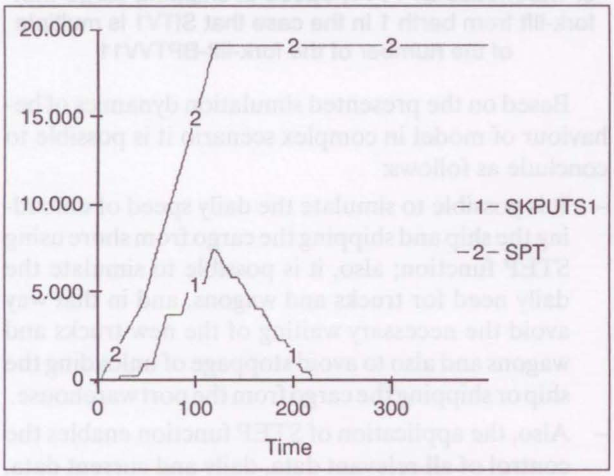

Figure 10 - State of the cumulative display of the loaded cargo to the warehouses-SKPUTS1, Current state of the cargo-SPT

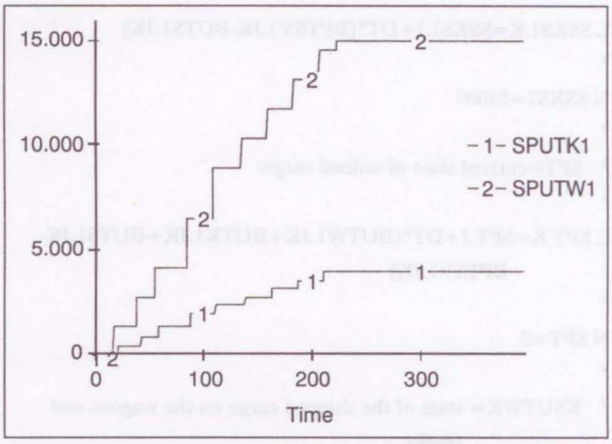

Figure 11 - Summary display of the loaded cargo on the trucks-SPUTK1, Summary display of the loaded cargo on the wagons-SPUTW1

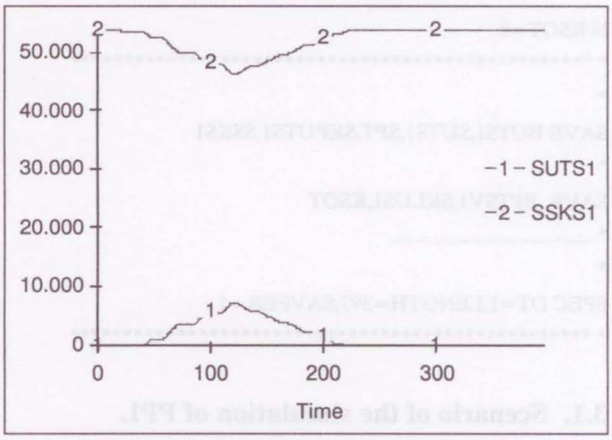

Figure 12 - State of available warehouse capacities-SSKS1, State of the loaded cargo to the warehouse-SUTS1

4. CONCLUSION

The application of the System Dynamics Simulation Modelling Approach of the complex marine dynamic processes, which the authors, together with their graduate students, carried out at the Maritime Faculty, University of Split – Croatia, seven years ago, revealed the following facts:

1. System Dynamics Modelling Approach is a very suitable software education tool for marine students and engineers.
2. System Dynamics Computer Simulation Models of marine systems or processes are very effective and successfully implemented in simulation and training courses as part of the marine education process.

This short presentation provides all the necessary information for the experts and the possibility to acquire additional information about the same system in fast, scientifically based way of investigation of complex systems.

Which means:

" Do not simulate behaviours dynamics of complex system using the so-called "black box" approach, because practice of education and designing of complex system confirmed that it is better to simulate using the so-called "white box" approach, e. g. System dynamics Methodology!"

Authors

Dr. sc. **JOŠKO DVORNIK**
E-mail: josko@pfst.hr
Dr. sc. **ANTE MUNITIĆ**
E-mail: ante.munitic@pfst.hr
Mr. sc. **MIRKO BILIĆ**
E-mail: mirko.bilic@pfst.hr
Sveučilište u Splitu, Pomorski fakultet
Zrinsko-Frankopanska 38, HR-21000 Split,
Republika Hrvatska

SAŽETAK

SIMULACIJSKO MODELIRANJE I HEURISTIČKA OPTIMIZACIJA TOKA MATERIJALA LUČKOG TERETNOG SUSTAVA

Simulacijsko modeliranje, uz dinamiku sustava i intenzivnu uporabu modernih digitalnih računala, što znači masivnu primjenu danas vrlo povoljnih i istovremeno vrlo moćnih osobnih računala (PC), jedan je od najpogodnijih i najučinkovitijih znanstvenih načina istraživanja dinamičkog ponašanja nelinearnih i kompleksnih: prirodnih, tehničkih i organizacijskih sustava. Metodologija dinamike sustava (prof. dr. J.Forrester – MIT), tj. relativno nova znanstvena disciplina, u prijašnjem je edukacijskoj i dizajnerskoj praksi pokazivala svoju učinkovitost u praksi kao vrlo pogodno sredstvo za rješavanje problema upravljanja, ponašanja, osjetljivosti, fleksibilnosti i osjetljivosti dinamike ponašanja različitih sustava i procesa. Sustavno-dinamička računalna simulacijska metodologija korištena je od 1991. do 2003. za modeliranje dinamike ponašanja velikog broja nelinearnih brodskih električnih, termo-dinamičkih, hidrauličkih, mehaničkih i pneumatskih sustava. Ovu metodologiju koriste studenti kao materijal za diplomske radove, i profesori Više pomorske škole i Pomorskog fakulteta u Splitu za realizaciju i objavljivanje rezultata znanstveno-istraživačkog rada. Svrha je ovog rada pokazati učinkovitost primjene simulacijskog modeliranja dinamike sustava u istraživanju dinamike ponašanja jednog lučkog prekrcajnog sustava prikazanog pomoću mentalno-verbalnih, strukturnih i matematičko-računskih modula, uz simulaciju prekrcajnih lučkih aktivnosti.

KLJUČNE RIJEČI

dinamika sustava, modeliranje, prekrcajni sustav, heuristička optimizacija, kontinuirana i diskretna simulacija, planer lučkog upravitelja

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