SYSTEM DYNAMICS MODELLING OF MATERIAL FLOW OF THE PORT CARGO SYSTEM

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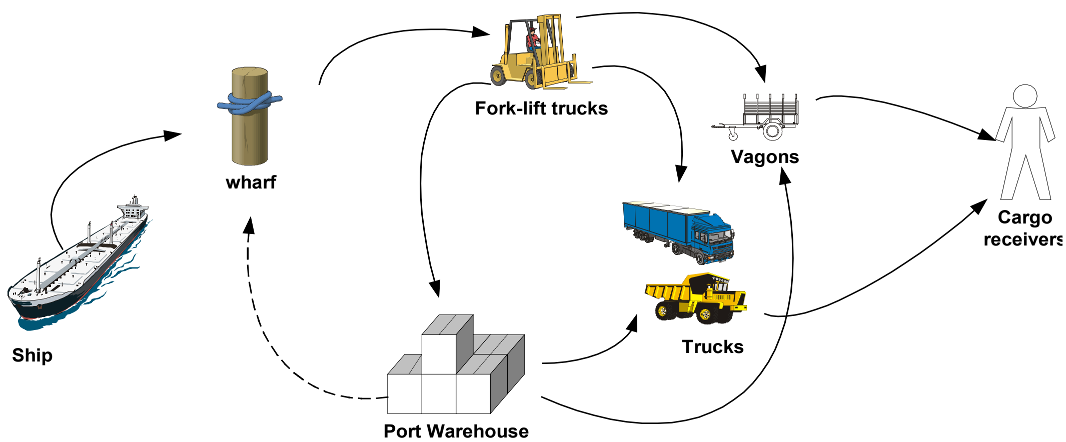

Structural model of material flow of the cargo

ABSTRACT

Simulation Modelling, together with System Dynamics and intensive use of modern digital computer, which mean massive application, today very inexpensive and in the same time very powerful personal computer (PC-a), is one of the most suitable and effective scientific way 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. relatively new scientific discipline, in former educational and designer practice showed its efficiency in practice as very suitable means for solving the problems of management, of behaviour, of sensibility, of flexibility and sensibility of behaviour dynamics of different systems and processes.
System Dynamics Computer Simulation Methodology have been used from 1991 to 2003 for modelling of dynamics behaviour of the large number of non-linear ship electrical,

thermo-dynamical, hydraulically, mechanical, pneumatically systems and managerial systems. This methodology is used by students as a material for graduate these, and for realization and publishing the results of scientific research work of 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 behaviors dynamics, one of the Port-Transshipment Systems be presented with mental-verbal, structural and mathematical-computing models, and it will simulate transshipment port working processes.

Key words: System Dynamics, Modelling, Transshipment System, Heuristic Optimization, Continuous and Discrete Simulation, Port Manager Planer.

1. INTRODUCTION:

The System Dynamics Modelling is in essence special, i.e. "holistic" approach to the simulation of the dynamics behaviour of natural, technical and organization systems. Systems Dynamic comprise qualitative and quantitative simulation modelling, and the concept of optimization of dynamic systems and processes is based on so call "heuristic" procedure. Meaning that on the method of manual and iterative procedure, which is automatized with the help of fast digital computer, named "heuristic optimization" (retry and error!). This simulation model is only one from the large number of made and educationally and practically used simulation models for education and training of young students – mariner, witch use so call "white box" philosophy of investigation of complex systems, as distinguished from "black box" approach! All simulation models made in last decade of past century on Maritime faculty Split, Croatia, are the component of scientifically macro project called: *Intelligent Computer Simulation of the Model of Marine Processes.*

2. SYSTEM DYNAMICS MODELLING OF THE PORT-TRANSHSHIPMENT SYSTEM

2.1. Qualitative Modelling of the Port-Transshipment System

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

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

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

Unloading/loading of the cargo in port is complex dynamics process with two subsystems:

- Unloading/loading of the cargo in port (BUTUL),
- Surrounding environment (OS).

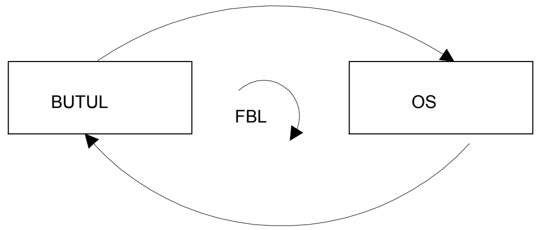

Figure 1. Rudimentary structural model of the Port-Transshipment System

Subsystem BUTUL have at least four sector 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, which are objective at disposal,
4. Warehouses (number and the area that are at disposal).

Subsystem OS have at least four sector i.e. subsections:
1. Waiting ship (on the berth or in arrival),
2. Engaged wagons capacities,
3. Engaged trucks capacities,
4. Consignee (receiver) of the cargo.

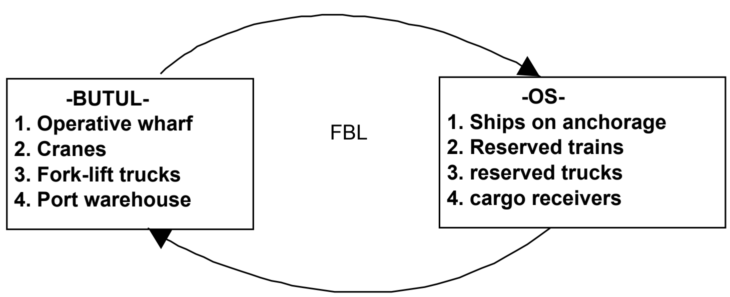

Figure 2. Structural diagram of depending BUTUL and OS model of the Port Transshipment System

This example of PPL presents 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) equipment that has 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, port-transport manager must give an order to stop the unloading of the ship. The unloading of the ship can start again when new equipment i.e. available transport capacities are reserved (in this case railway and road vehicle).

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

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

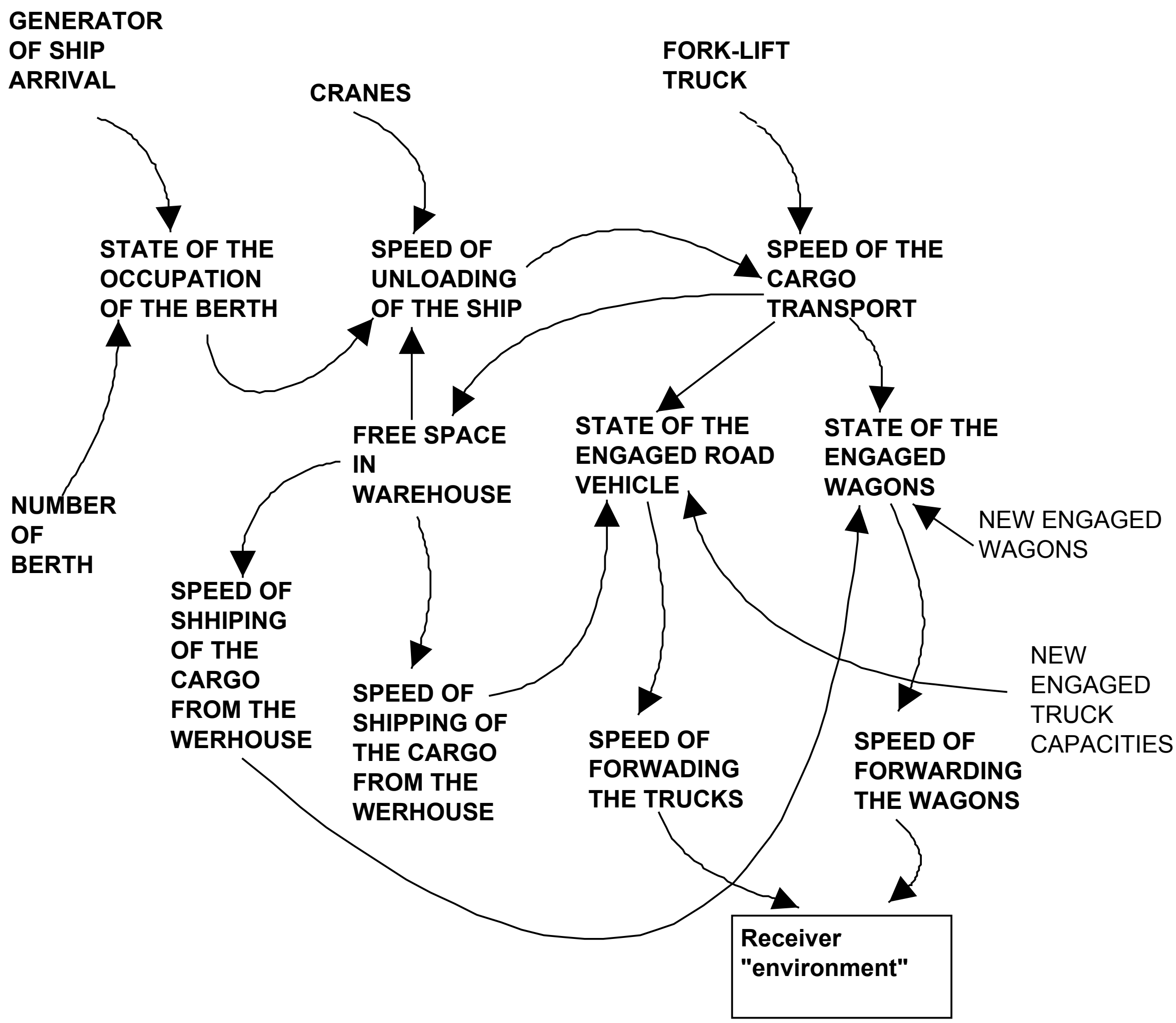

Figure 3. Material and information flows of the PTSS and environment

"Generator of ship arrival" is fictitious exogenous source of ship cargo (new arriving ship), which is possible to realize 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” depend on “state of busyness of the berth” and on number of i.e. “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 "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 if there is free space in it).

Unloaded cargo is directed to railway platform, i.e. cargo is loaded in available railway capacities that have been reserved in advanced (24h).

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

If in limited time of one-day i.d. 24 hours of continually unloading of ship cargo all available road vehicle are used (daily reserved contingent) and new contingent of railway wagons doesn't follow, then port-transport manager gives an order to start temporally storage of unloaded ship cargo until there is free space in warehouse.

In case we don't have planed (daily reserved in advance) loading on disposal i.e. railway, road and storage capacities, port manager gives an "expensive" order, i.e. he has to stop the unloading of the ship cargo until the new railway or road transport contingent which is daily reserved in advance arrive.

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

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

"Expert-logical" material flow of unloaded cargo is divided in three available and possible loading i.e. placing of the cargo that has been brought with fork-lift truck in: 1. Daily reserved railway wagon capacities, and if they aren't sufficient to load already unloaded cargo on berth 1 (24-hour working day), then: 2. In advanced 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, and if it is possible this should be avoided, which is: 3. in free storage space!

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

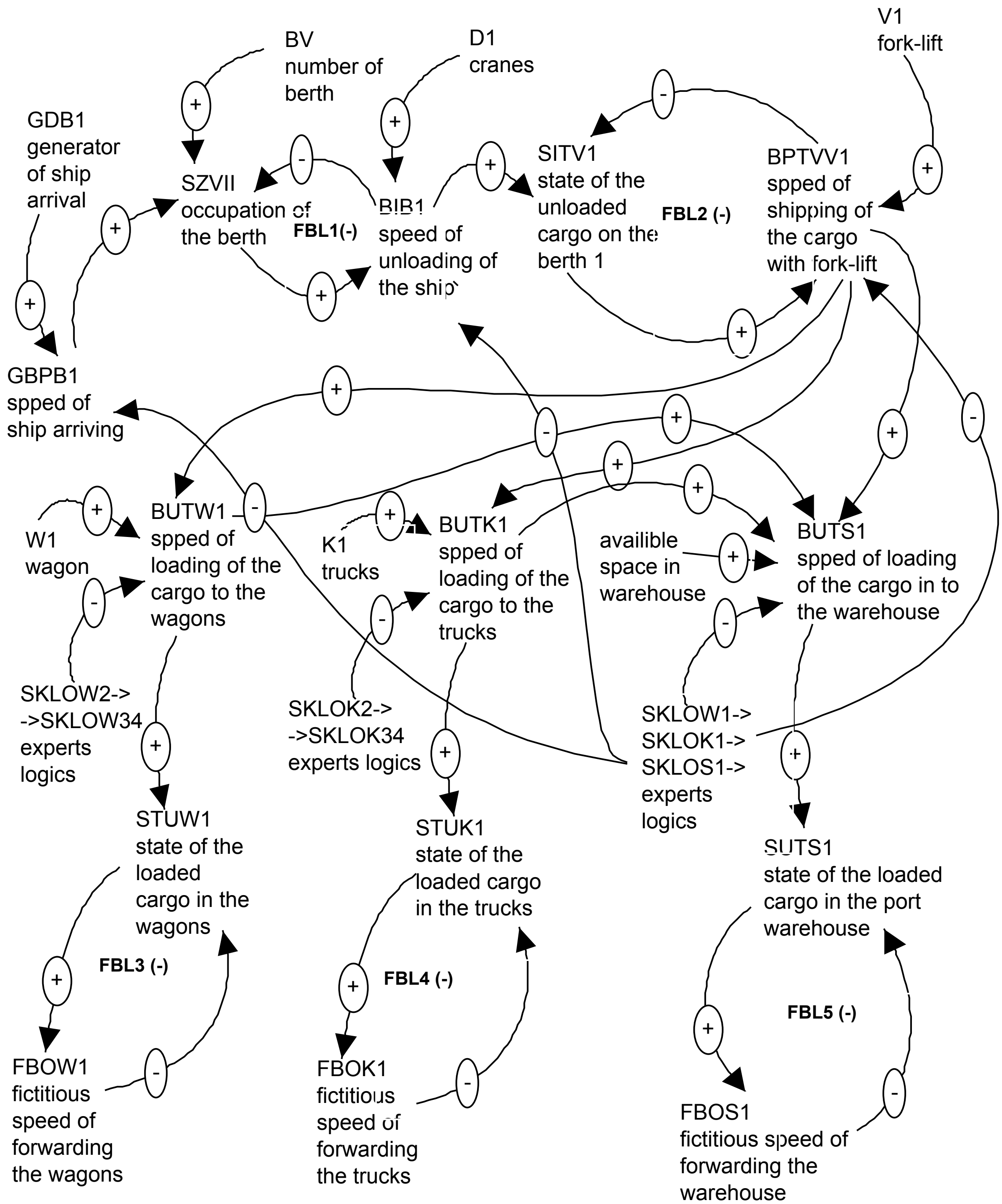

Figure 4. System Dynamics structural simulation model of the PPL-a

Five reflexive circles dominate in System Dynamics structural simulation model of the PPL-a: **(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 the 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 of the warehouse)(+)➔(-) SUTS1(state of the unloaded cargo in the port Warehouse).

c) Structural flow diagram in POWERSIM symbolic:

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

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

Where are:

GDB1= generator of ship arrival,
BPB1= speed of putting to shore ship,
SZV1= state of occupation of the berth,
BIB1= speed of unloading the ship,
D1=number of cranes,
SITV1= state of the unloaded cargo on the berth 1,
BPTVV1= speed of shipping of the cargo with fork-lift from the berth1 to the platforms for loading on the wagons, trucks or warehouse
BPTVV11= speed of shipping of the cargo with fork-lift from the berth 1 in the case that SITV1 is multiple of the number of the fork-lift
V1=number of fork-lift,
SKLOS1= conditional logical function that limit filled warehouse,
SUTS1= state of the loaded cargo on 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 need for loading the cargo to the wagons,
GDW1= generator of wagons arrival in 24H,
STUW1= state of the loaded cargo on 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 need for loading the cargo to 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 limit 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 transshipment from warehouse,
SSKS1= state of available warehouse capacities,
SPT= current state of unload cargo,
KSOT= cumulative book-keeping state of the shipped cargo.

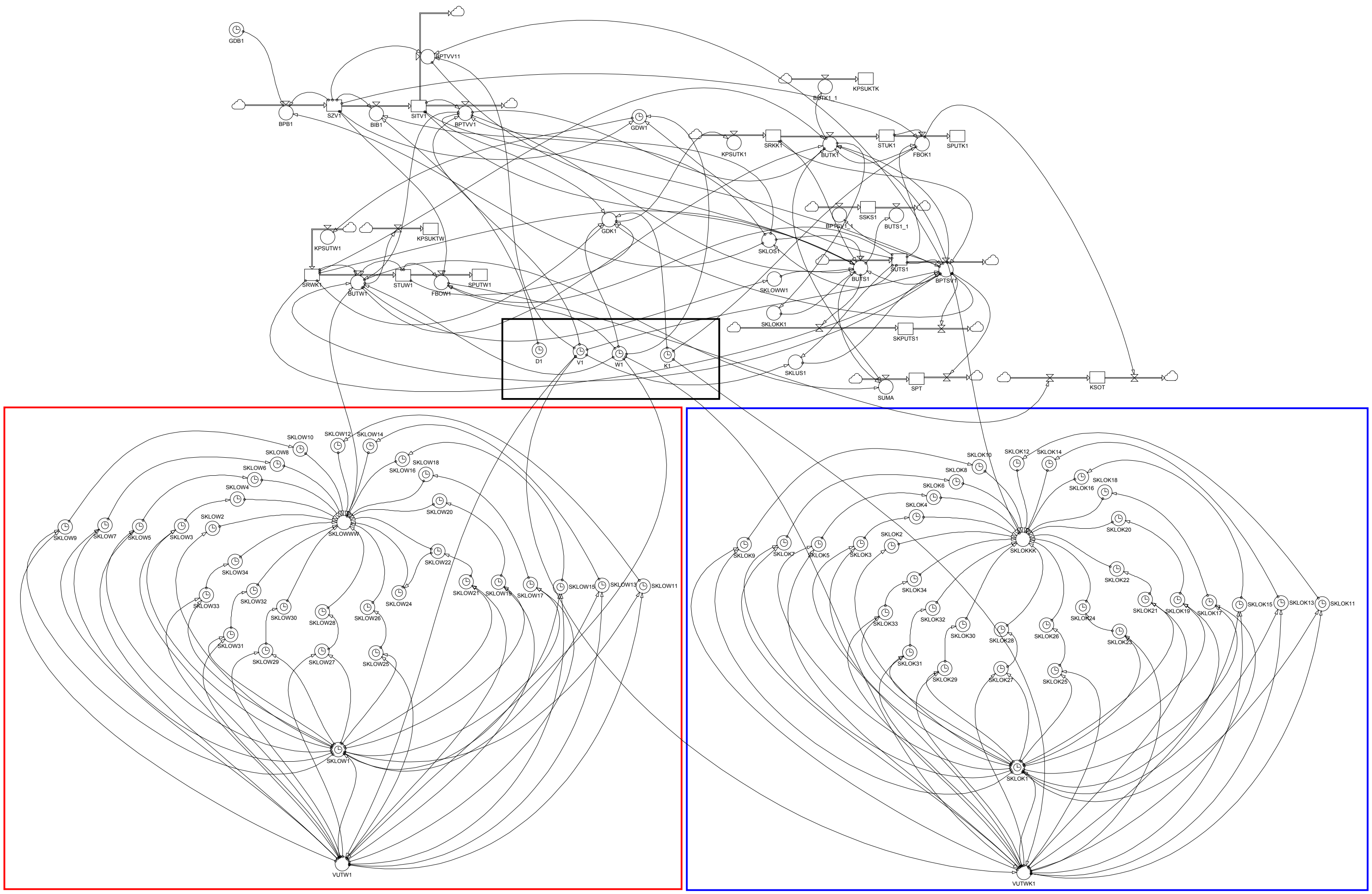

Figure 5. Complete SD diagram of flow diagrams of simulation model of the PPL-a (POWERSIM)

3. COMPUTER SIMULATION MODEL OF THE PPL-a

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

```
* 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.
*                       (TONA/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.
*                (TONA/h)
*                CLIP=function of limitation
*                GDB1= generator of ship arrival on berth 1.
*                (TONA/h)
*            SZV1= state of occupation of the berth 1.(TONA)
*                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.(TONA)
*   SZV1= fictitious state of occupation of the berth 1.(TONA)
*   SZV1=0=initial state of the berth 1.(TONA)
*     DT=basic time step for computing the iteratie.(h)
*   BPB1= speed of putting to shore ships (TONA/h)
*    BIB1= speed of unloading  the ship on the berth1.
*                (TONA/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 (TONA/h)
*      D1=number of the cranes  (PIECE)
*   SZV1= fictitious state of occupation of the berth 1.(TONA)
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.(TONA)
*     BIB1= speed of unloading of the ship cargo on the berth1
*                (TONA/h)
*  BPTVV1= speed of shipping of the cargo with fork-lift from
              the  berth1 (TONA/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 (TONA/h)
*             V1=number of the fork-lift (PIECE)
*    SITV1= state of the unloaded cargo on the berth 1(TONA)
*  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 the 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.  (TONA/h)
*  BPTVV1= speed of shipping of the cargo with fork-lift from
                 the berth 1.
*            (TONA/h)
*      STUW1= state of the loaded cargo on the wagons within
                  24 (TONA)
*      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+
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            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)
+PULSE(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,
1,239,2400)+PULSE(25*W1.K,1,263,2400)+ PULSE(25*
W1.K,1,287,2400)+PULSE(25*W1.K,1,311,2400)+PULSE(2
5*W1.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(TONA)
*                     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
*                   (TONA)
*   BUTW1= speed of loading of the cargo on the wagons on
*              berth1. (TONA/h)
*  FBOW1=fictitious speed of forwarding the wagons in 24 H.
*                     (TONA/h)
*   STUW1=0= initial state of the loaded cargo on the wagons.
*                     (TONA)
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
*                     (TONA)
*   STUW1= state of the loaded cargo on the wagons in24H
*                     (TONA)
*         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      (TONA)
*   FBOW1= fictitious speed of forwarding the wagons in 24H
*                     (TONA)
* SPUTW1=0= initial state of the loaded cargo on the wagons.
*                     (TONA)
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 the loading the cargo on to 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 laoding of cargo to the trucks from the
*              berth 1.   (TONA/h)
*   BPT= speed of shipping of the cargo with fork-lift from the
*              berth 1.  (TONA/h)
*     BUTW1= speed of laoding of cargo on the wagons from
*              the berth 1.  (TONA/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(TONA)
*                        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
             (TONA)
*   BUTK1= speed of laoding of cargo on the trucks (TONA/h)
*   FBOK1= fictitious speed of forwarding the trucks in 24 H.
*                    (TONA)
*    STUK1=0= initial state of the loaded cargo on the trucks
*                    (TONA)
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.
*                    (TONA)
*      STUK1=0= initial state of the loaded cargo on the trucks
*                    (TONA)
*             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 (TONA)
*     FBOK1= fictitious speed of forwarding the trucks in 24
*                  H.(TONA)
* SPUTK1=0= initial state of the loaded cargo on the trucks
                  (TONA)
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
*                    (TONA/ h)
*    BPTVV1= speed of shipping of the cargo with fork-lift
*                   from the berth1  (TONA/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 (TONA/ 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 (TONA/ h)
A SKLOS1.K=CLIP(0,1,SUTS1.K,54000)
*               SKLOS1= conditional complex logical function
* SUTS1= state of the loaded cargo on the warehouse (TONA)
*                  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 (TONA)
* BUTS1= speed of loading of  cargo to the warehouse
*               (TONA/ h)
*   SUTS1= 0= initial state of the loaded cargo to the
*                    warehouse (TONA)
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-a

This model includes putting to shore and unload of the ship on the berth, transshipment of the cargo on the wagons with subsection of logical management built in it, transshipment of the cargo on trucks also with subsection of logical management, an at the end transshipment of the cargo to the warehouse.
In this paper, cause of its largeness, we will present only zero scenario with initial conditions:

- ship is on the berth 1,
- unloading of the ship have been started in time T=0,
- Transshipment of the 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
- Transshipment of the cargo on the fork-lift, and the number of fork-lift are V1= 2+STEP(2,47)-STEP(2,119), i.e. the capacities of the cranes are 50*V1
- Transshipment of the cargo with fork-lift from the berth to the gate and transshipment on the wagons, and the number of wagons are W1= 56+STEP(40,71)-STEP(40,119)
- transport of the cargo on the 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:

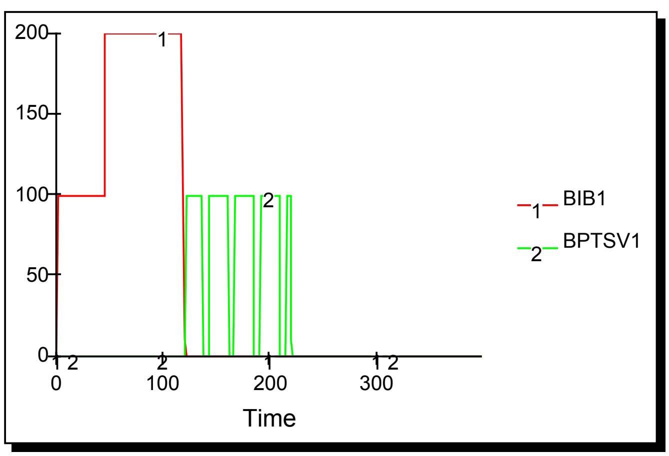

Figure 6.: Speed of unloading the ship-BIB1, Speed of shipping of the cargo to the warehouse-BPTSV1

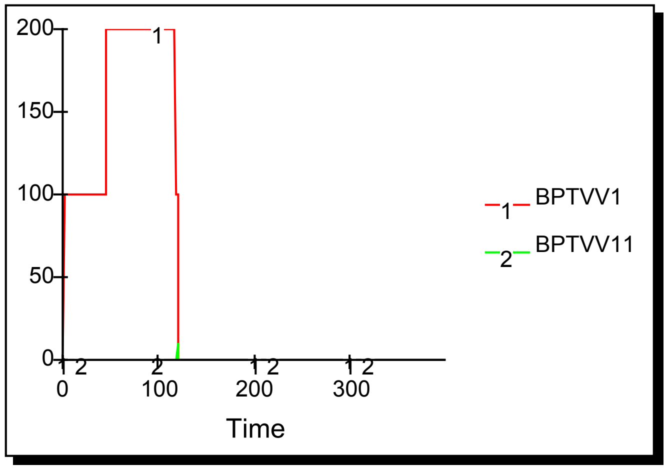

Figure 7.: Speed of shipping of the cargo with fork-lift from the berth1 to the platforms for loading on the wagons, trucks or warehouse-BPTVV1, Speed of shipping of the cargo with fork-lift from the berth 1 in the case that SITV1 is multiple of the number of the fork-lift-BPTVV11

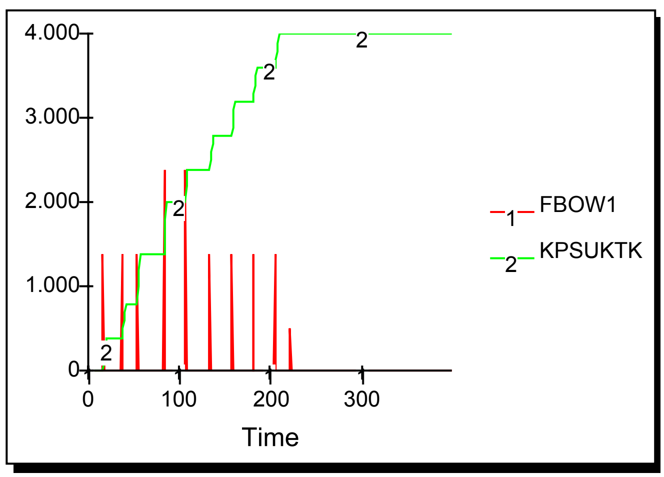

Figure 8.: Fictitious speed of forwarding the wagons in 24 H-FBOW1, Cumulative display of the state of the loaded cargo on the trucks-KPSUKTK

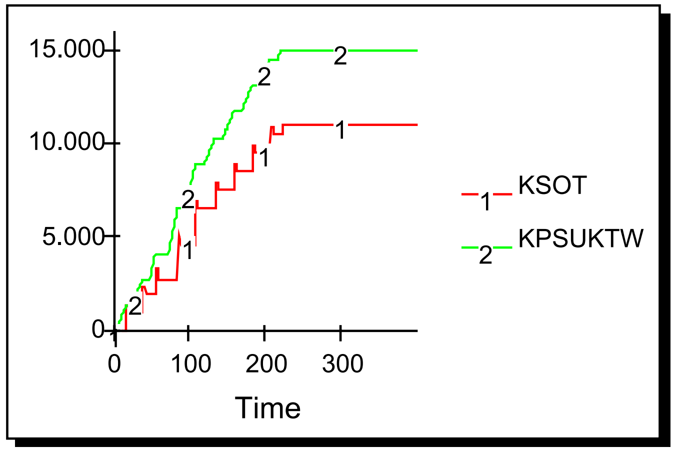

Figure 9.: Cumulative display of the state of the loaded cargo on the wagons-KPSUKTW, Cumulative book-keeping state of the shipped cargo-KSOT

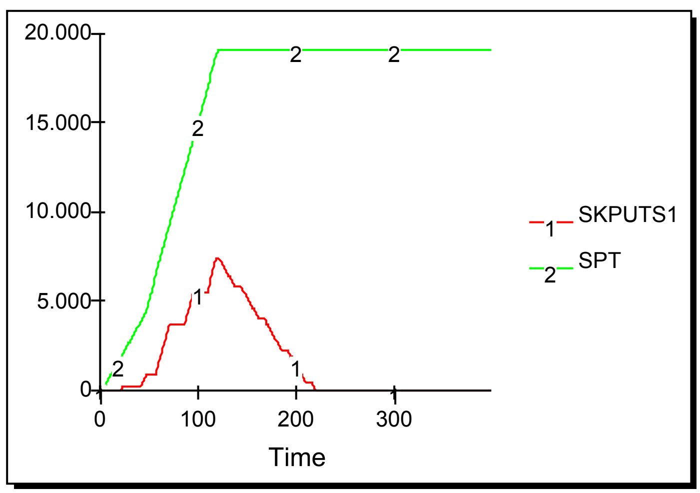

Figure 10.: State of the cumulative display of the loaded cargo to the warehouses-SKPUTS1, Current state of the cargo-SPT

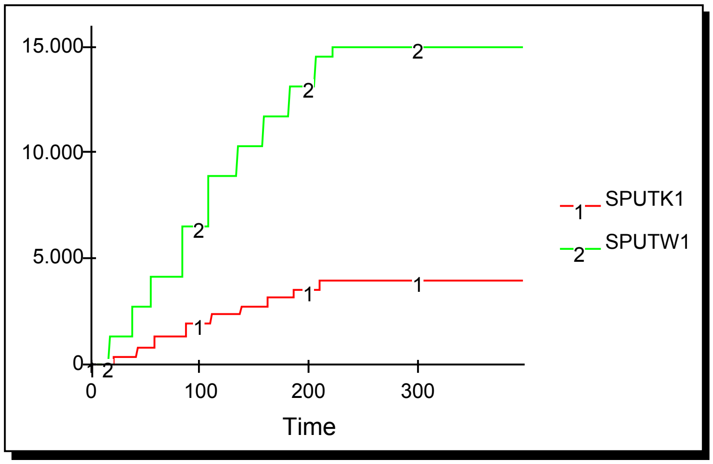

Figure 11.: Summary display of the loaded cargo on the trucks-SPUTK1, Summary display of the loaded cargo on the wagons-SPUTW1

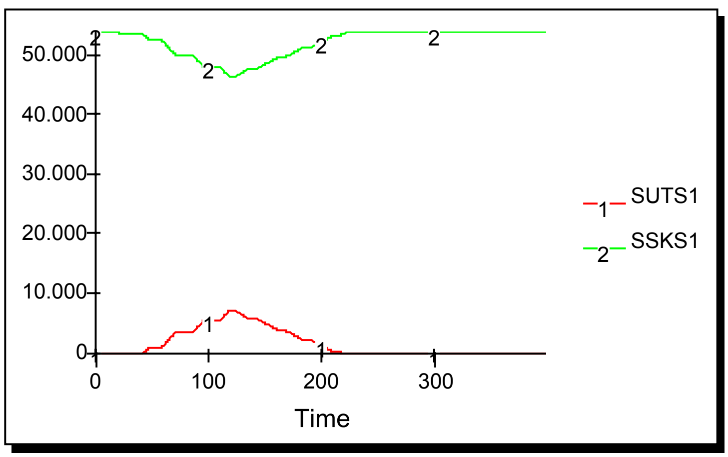

Figure 12.: State of available warehouse capacities-SSKS1, State of the loaded cargo to the warehouse-SUTS1

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

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

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

4. CONCLUSION

The application of 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:

l. The 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.

In this short presentation are given all necessary information for expert and possibility to acquire additional information about the same system in fast, scientifically based way of investigation of complex system.
Which means:

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

Authors

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