To Main Proceedings Document

Is the LYNEIS-model reproducible ?

Prof. Dr. Dr. Rainer Schwarz

Chair of Managerial Economics, Management Accounting and Managerial Control

Dipl.-Betriebswirt (FH) Peter Maybaum

Systems Engineer at the Chair of Managerial Economics, Management Accounting and Managerial Control

Brandenburg Technical University of Cottbus
Department of Mechanical, Electrical and Industrial Engineering
03013 Cottbus / Germany
Tel. +49 355 / 69 2389
Fax. +49 355 / 69 3324
Email: schwarz@tu-cottbus.de
Email: maybaum@tu-cottbus.de
URL: http://www.wiwi.tu-cottbus.de/controlling

1. Introduction

There are several databases with time series of financial variables of companies. We have worked with the Bonner Datenbank containing time series of approximately 700 German firms over a period of 40 years.[1] The paper is a challenge to look for a model describing the behaviour of such a firm and at the same time explaining it within the conceptual framework of the theory of the firm. This theory presents mainly static models. Models are build in the econometric tradition - if time is incorporated at all. We are challenged by separated bodies of knowledge: empirical time series, a static theory of the firm, and some dynamic models (mainly considering parts of a firm but not his complex business dynamics). In an attempt to bridge this gap we tried to use the relatively complex model of LYNEIS (1980). Here we report first results of our attempt to reproduce the structure and the behaviour of that model.

Trying to reproduce the results of other scientists is a common method of validation and scientific progress in many empirical sciences (i.e. physics). If somebody claims having discovered cold fusion he has to present the detailed description of the experiment, equations, software, i.e. all elements needed to reproduce the same effect or behaviour. Every laboratory in the world will hurry up to repeat that effect: to check if there is really cold fusion under that circumstances or - confusion. This approach is used in system dynamics on the enterprise level almost exclusively for that part of industrial dynamics, which is embedded in the beer game. Structure and behaviour are repeated by different members of the SD community.

Compared to other model descriptions of business dynamics LYNEIS gives many prerequisites needed for an attempt to reproduce his model. He defines variables and presents equations, some assumptions and interpretations, the computer program of the final model and time behaviours of variables to the scientific community which can be used in the work of other members of that community.

Approaching our question we proceed as followed. In the next section we outline briefly the basic structure of the model with a focus on core variables of the building blocks. Then we present simulation results of a core block: the two-stage inventory system. We use the same equations but a different software (POWERSIM, whereas LYNEIS used DYNAMO). The forth section draw on some difficulties we encountered. Here we argue that the model equations developed in the chapters of the book (building blocks) are different from that in the DYNAMO computer program of the final complex model. Then we show results for the final model (consisting of all blocks). The simulation of the complex enterprise model presents patterns of unstable behaviour (a phenomenon similar to national economic models). We discuss some problems and possible reasons. Finally we propose to work on a reduced model structure and to connect it with propositions or causal relations of the theory of the firm or the German Betriebswirtschaftslehre.

2. Outline of the basic model structure

The model has the following building blocks: two-stage inventory system (ch. 4,5), connected with parts supplier sector (ch. 6), labour sector (ch. 7), market interaction sector (ch. 8), accounting sector (ch. 9, 10), capital equipment sector (ch. 11) connected with financial resources (ch. 12), professional resources (ch. 13). This section has a focus on variables, which are essential for the block structure and at the same time have an influence on the structure of other blocks. We hope to achieve by this approach a sharper comprehension of the connections between the blocks of the model.

The core variables of the inventory system (Fig. 1) constitute a physical flow (solid lines) from parts order rate (POR) through parts inventory (PI), work in process (WIP) and finished inventory (FI) to shipment rate (SR). The production rate (PR) is influenced by information (dashed lines) about customer order rate (COR), work in process (WIP) and finished inventory (FI), the parts order rate (POR) by parts inventory (PI) and production rate (PR). (Here and in the following outline intermediary, supplementary or more detailed variables are omitted.)

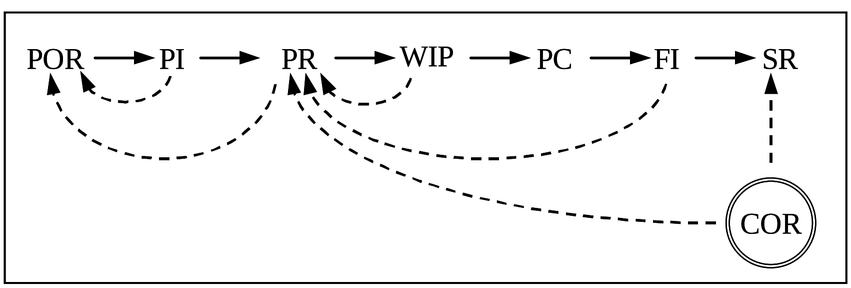


Fig. 1: Core variables of the two-stage inventory system

In chapter 5 this structure is slightly modified when trend forecasting in determining PR and POR is introduced. This block is then connected to the parts supplier sector. Now the production rate is determined differently (Fig. 2) by the desired production rate (DPR, incorporating the former influences on PR) and the effect of parts inventory level (EPILPR). The other features of the inventory system are the same as in Fig. 1.

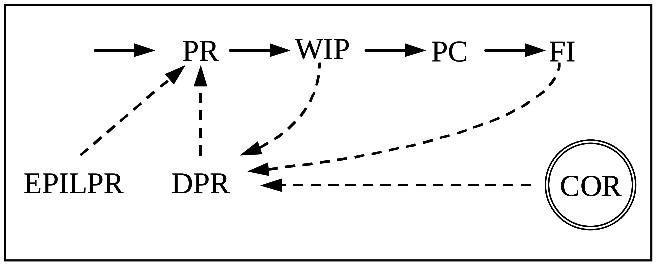


Fig. 2: Core variables of the two-stage inventory system with trend forecasting

Within the labour sector the influence structure on PR changes (Fig. 3). The potential output from labour (POL) determines, together with EPILPR the production rate. DPR now has an indirect influence intermediated mainly by labour (L) and overtime (OT). Both of them plus labour productivity are the decisive influences on POL. A lot of other variables influence the magnitude of labour as well but have to be omitted here (as indicated by the dotted arrow left down).

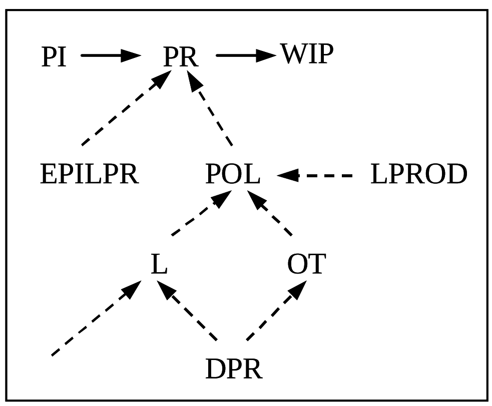


Fig. 3: core variables of the labour sector

In chapter 8 company-market interaction are modelled. Customer order rate (COR) is now determined by market share (MS) and market demand (Fig. 4). The influences on MS are described in greater detail. DPR is now the only factor determining PR directly, i.e. without the influences of labour and labour productivity (as compared with Fig. 3). On the other hand the influence of COR on DSR is now mediated trough UO (unfilled orders).

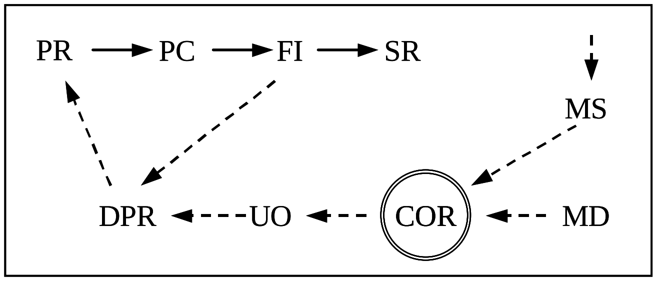


Fig. 4: Core variables of the market interaction sector

In the accounting sector the physical variables are multiplied by costs or prices:
- The sum of FI, PI and WIP multiplied by their costs gives the value of inventory,
- SR multiplied by prices gives the value of sales,
- Labour and overtime determine labour cost (LC) regarding average salary,
- PS and LS determine value added in assembly.

There are much more monetary or value variables and their relations. We suspend a deeper analysis of this sector in this paper. Firstly it seems that the monetary expressions are consequences of the time behaviour of physical variables on which we focus here. Secondly we have to reconsider the way fixed costs are defined by LYNEIS: they are a fixed percentage of the average dollar value of sales. This means they are variable depending on output (sales) in the case of constant prices. In our understanding fixed costs are those one has to bear even when there is no output.

Chapter 10 does not present a separate building block but rather a table function for the effect of financial pressure (EFDPR) on desired production rate (DPR) and parts order rate (POR), see Fig. 5. There are no hints on a connection to other blocks but a lot of figures with the time behaviours of variables described in other building blocks.

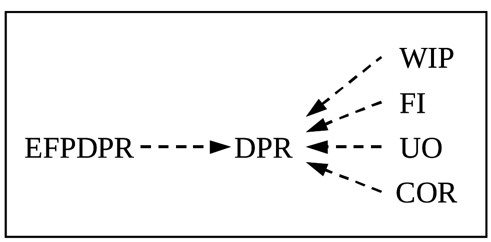


Fig. 5: Financial control of inventory system

The effects of the labour sector were based on the assumption that capital equipment (CE) does not constrain production. The building block of capacity expansion considers such effects. Fig. 6 shows the physical flows from capital equipment orders (CEO) to capital equipment scrappage (CES) and the information effects of capital equipment (CE) on production rate (PR).

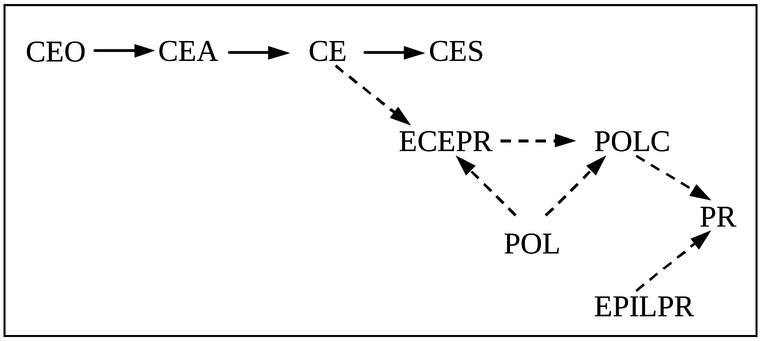


Fig. 6: Core variables of capacity expansion

The corresponding financial needs for capacity expansion are considered in chapter 12, which differs from the others. There are no variables or equations, which could be connected to other blocks or be interpreted in the context of that SD-company-model. Moreover: Here PR influences UO. In the market sector (Fig. 4) the opposite holds. We are not sure if this is a hidden (by LYNEIS) loop or a contradiction. Because of the missing equations we do not try to decide it. For different reasons we cannot draw on the content of chapter 13 either. This sector (professional resources) exercises an impact only on the market share (MS). Therefore this block is very loosely coupled with the variables determining the evolution of the firm, measurement problems of that impact not to mention.

3. Reproduction of the two-stage inventory system

On the basis of the detailed model structure of that system and the corresponding equations of chapter 4 we elaborated the following structure of variables in POWERSIM (Fig. 7). This structure can be regarded as the core building block of the company model proposed by LYNEIS.[2] The time behaviour of the POWERSIM-simulation is shown in Fig. 8. If one compares this result with the result of LYNEIS (Fig. 9) one can find only minor differences. On the whole the result is that this core building block can be reproduced. The investigation of the differences needs further research. One of the possible reasons can be the differences in the used software: DYNAMO versus POWERSIM. It is well known that even different standard econometric software packages present “serious numerical discrepancies” for identical data sets.[3]

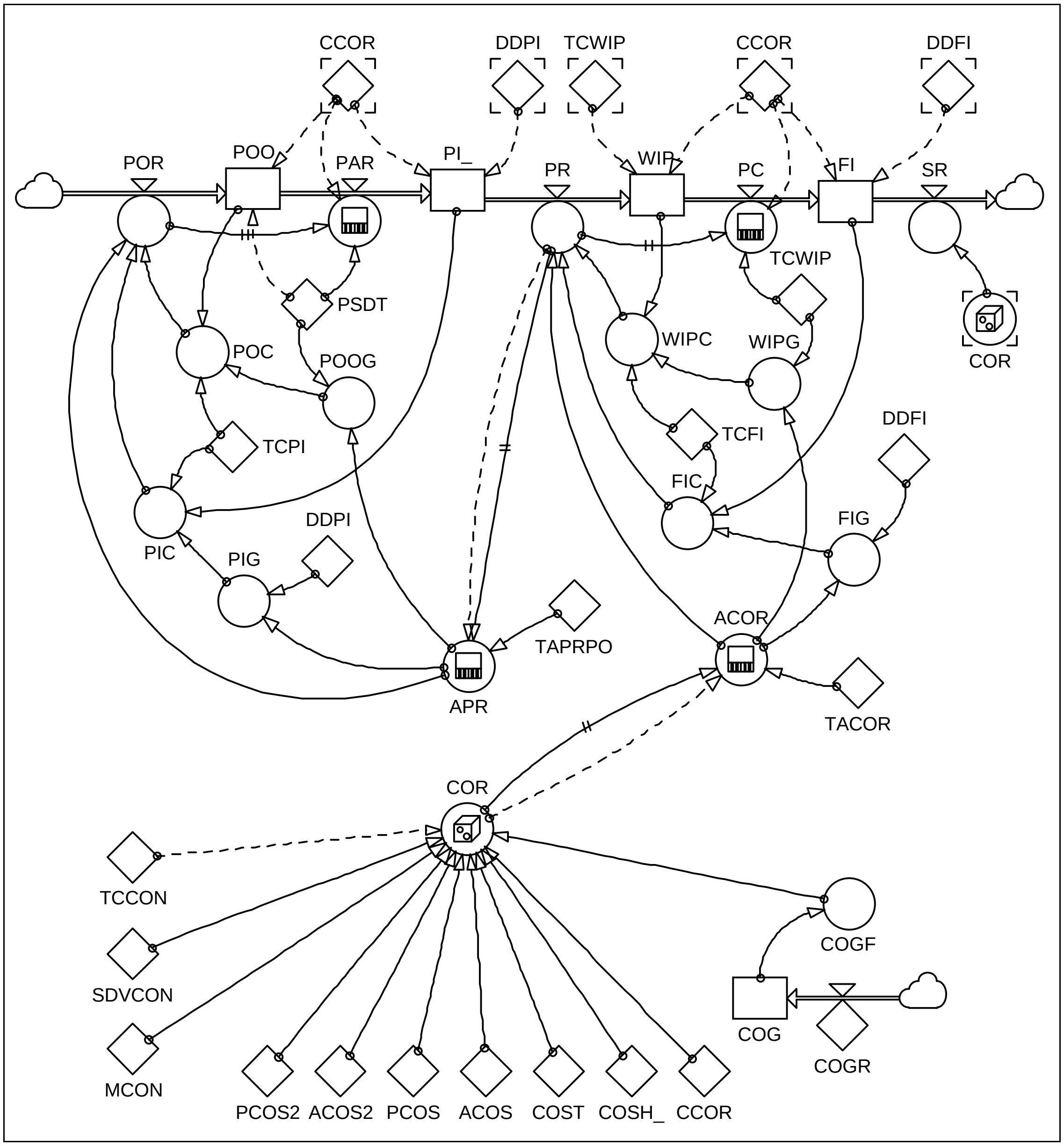
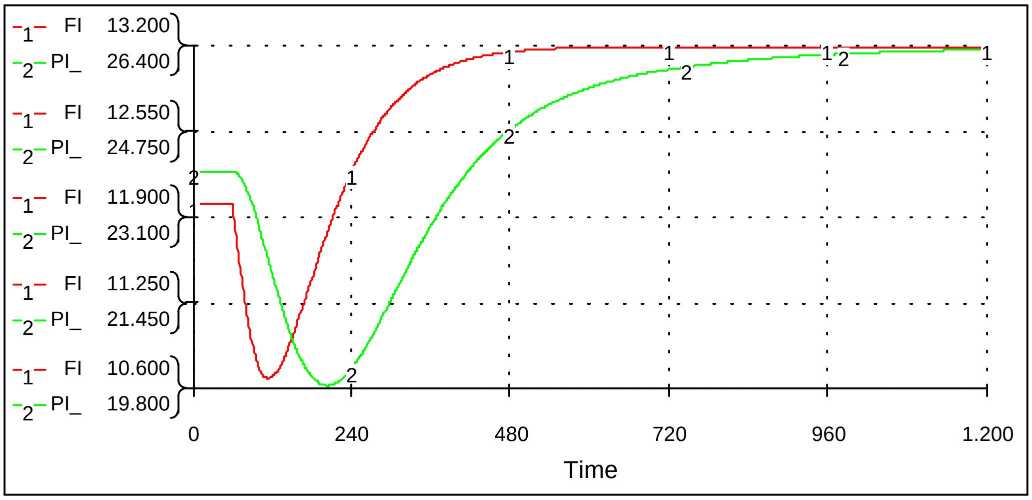
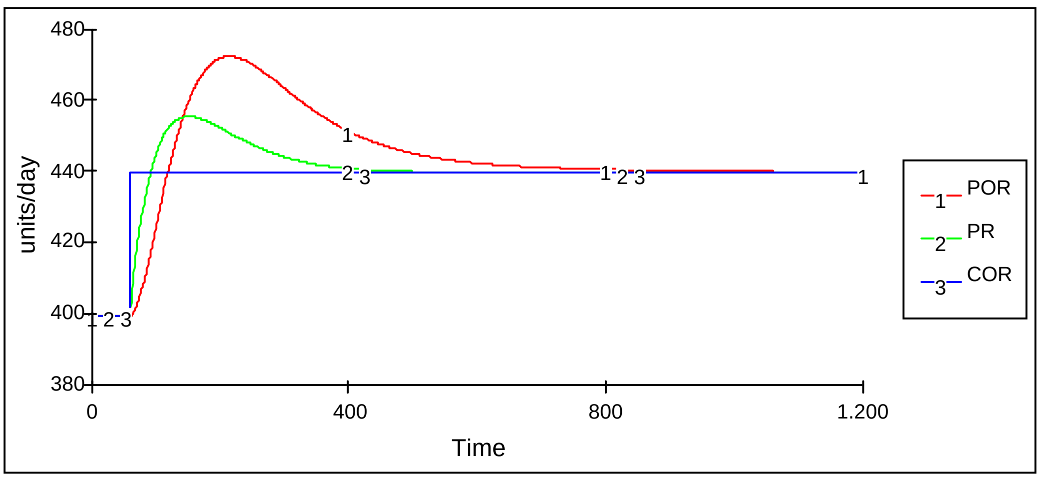


Fig. 7: Model structure of LYNEIS' core building block in the POWERSIM-description (for equations see Appendix I)



FI – finished inventory   PI – parts inventory



POR – parts order rate   PR - production rate   COR – customer order rate

Fig 8: Behaviour of POR, PR and COR in the two-stage inventory system.

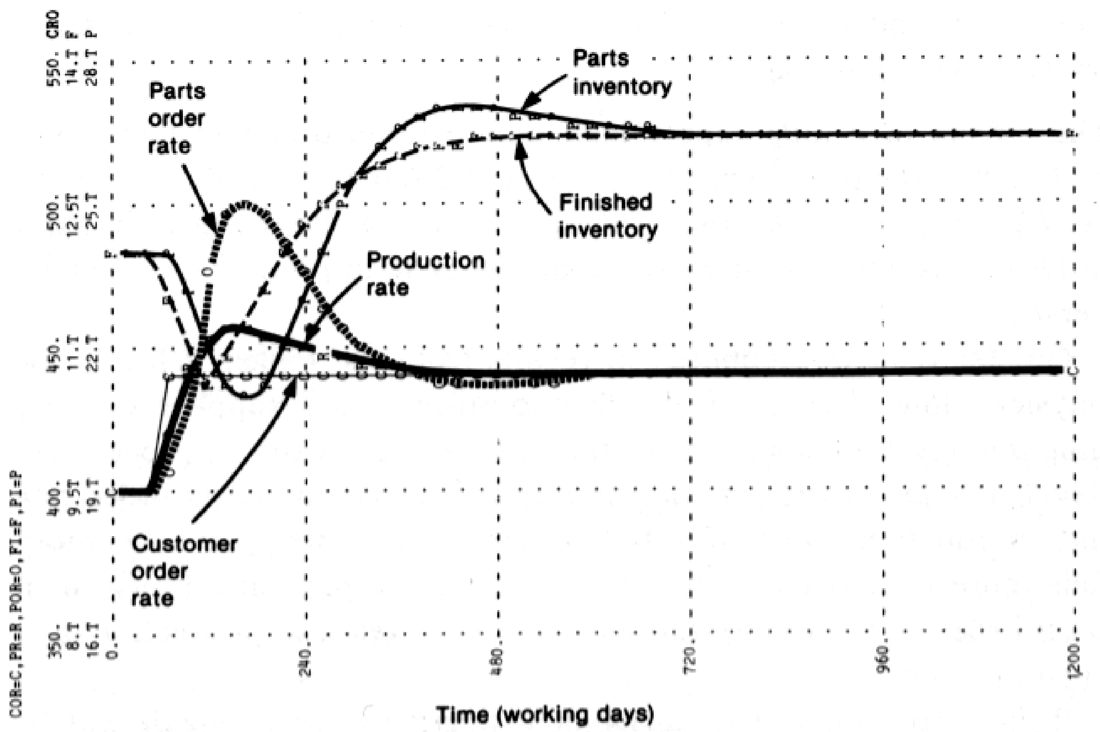


Figure 4.2 Inventory system response to a 10 percent STEP increase in customer order rate

Fig. 9: Result of LYNEIS

4. Can the building blocks be connected ?

Our effort to connect the building blocks of LYNEIS (as described in the chapters of the book) into one final company model had no positive result. The reasons of our problems are already indicated in the quite different influence diagrams of section 2. In other words the dynamic of some parts of the company is traced by LYNEIS in different building blocks. Their dynamicis explained by different variables, which are defined by different equations. It is difficult to find connecting variables between the building blocks. Here we underline this statement by repeating the equations for the production rate (PR) as used in different chapters or building blocks.

1.Production rate in policy design example (ch.3)

Equation 9 defines production rate (PR) to equal constant production rate (CPR) multiplied by a STEP change in production rate (SPR) and by a RAMP change in production rate RPR:

PR = CPR * SPR * RPR

2.Production rate in the two-stage inventory model (ch.4)

Production rate is set equal to the sum of average customer order rate (ACOR), finished inventory correction (FIC), and work in process correction (WIPC):

PR = ACOR + FIC + WIPC

3.Production rate in the two-stage inventory model with forecasting (ch.5)

The revised equation 8 states that production rate (PR) equals the sum of base customer order rate (BCOR), finished inventory correction (FIC), and work in process correction (WIPC):

PR = BCOR + FIC + WIPC

4.Production rate in the two-stage inventory model influenced by suppliers (ch.6)

Equation 7 states that production rate (PR) equals desired production rate (DPR) multiplied by effect of parts inventory level on production rate (EPILPR):

PR = DPR * EPILPR

5.Production rate in the labour model (ch.7)

Equation 5 states that production rate (PR) equals the product of potential output from labour (POL) and effect of parts inventory level on production rate (EPILPR):

PR = POL * EPILPR

6.Production rate in the capacity expansion model (ch.11)

In equation 5 production rate (PR) is defined to equal potential output from labour and capital (POLC) multiplied by effect of parts inventory level on production rate (EPILPR). POLC represents the production rate achievable with the available labour, overtime, and capital equipment, assuming adequate parts inventory. Shortages of parts inventory cause PR to fall below POLC:

PR = POLC * EPILPR

In the light of our effort to understand the LYNEIS model we cannot say : « Within each chapter the model developed builds on the model developed in the preceding chapter. » (LYNEIS, 1980, XV)

5. On the reproduction of the final company model

Finally we decided to look for the company model not in the chapters of LYNEIS' book but in the 27 pages of appendix C and D. That complex model has 393 variables. Our translation of the DYNAMO program into POWERSIM can be seen in appendixes II and III. Here the model blocks have indeed a very different outlook. Whereas LYNEIS did not present any behaviour figures for his final model we do. But the graphs of our simulation runs with the final model (for instance Fig. 10, 11, 12, 13, 14, 15) are at this stage of our work not very encouraging.

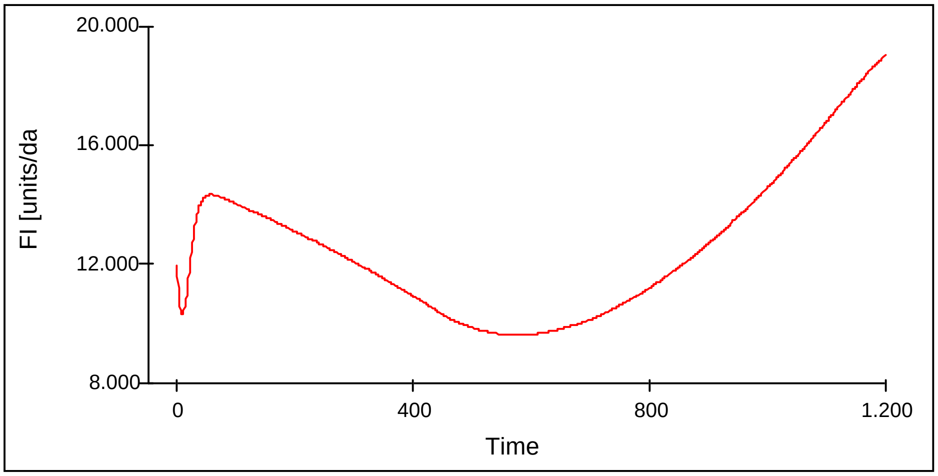


Fig. 10: Time behaviour of finished inventory (FI)

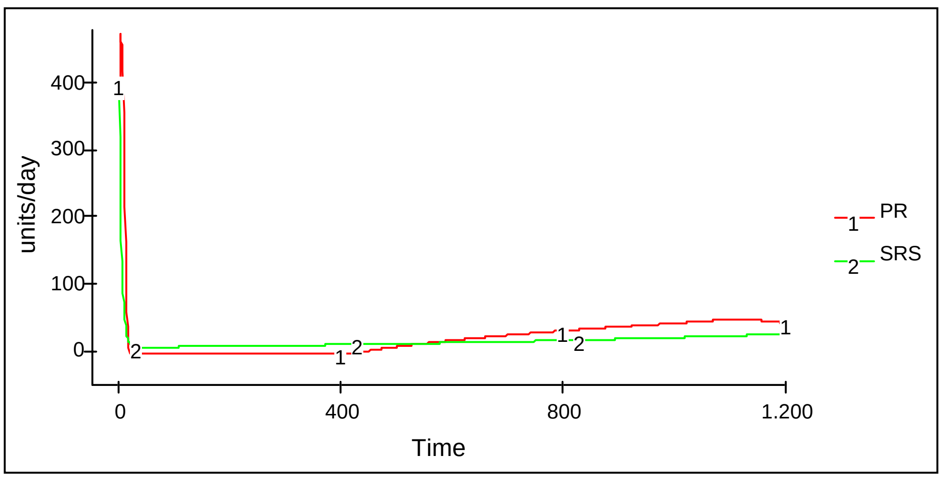


Fig. 11: Time behaviour of production rate (PR) and shipment rate from stock (SRS)

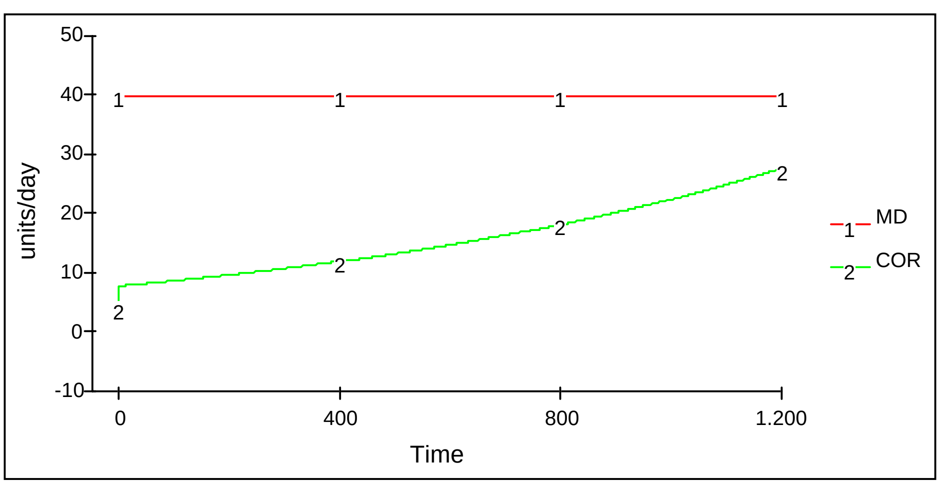


Fig. 12: Time behaviour of market demand (MD) and customer order Rate (COR)

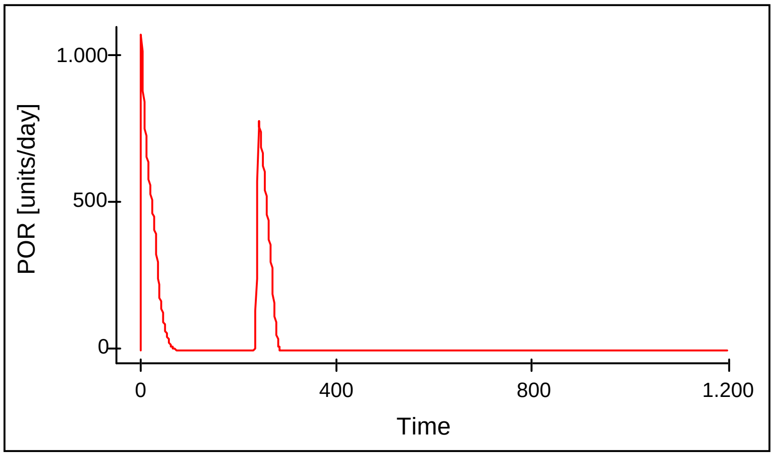


Fig. 13: Time behaviour of parts order rate (POR)

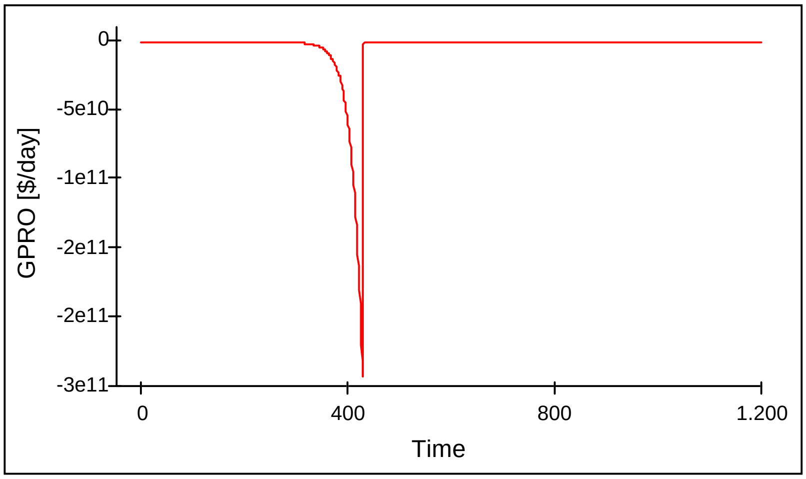


Fig. 14: Time behaviour of gross profits (GPRO)

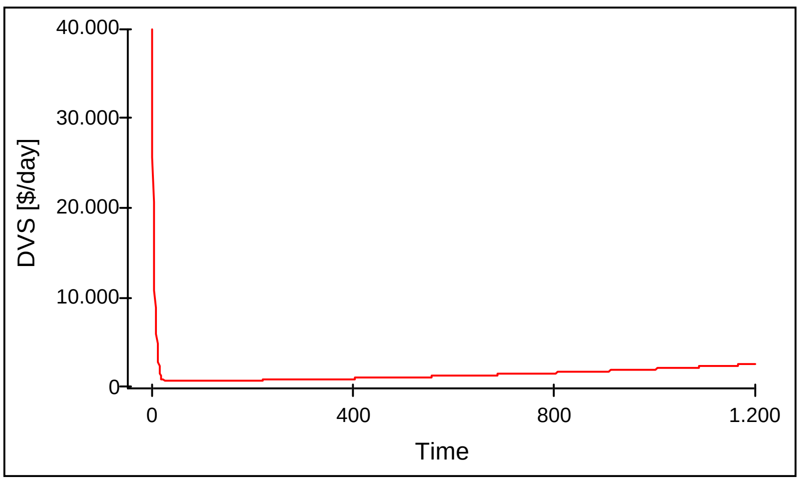


Fig. 15: Time behaviour of dollar value of sales (DVS)

It is very difficult to explore the reasons of this model behaviour, especially when one has to reconstruct the meaning, values and interpretation of 393 variables only from a DYNAMO program listing. With the aim of beginning a discussion we are wondering about some features of the modelled company which can be found in the start-up conditions, assumptions and time behaviours.

The firm produces only one type of product which does not change over 5 years (Therefore we neglected the professional resource sector in the final model. R&D is in economic theory and praxis only needed if it has an innovative effect.) In the beginning the firm employes 400 persons. One person is producing on one unit of capital equipment (machine) one unit of the product per day. Market demand does not change over 5 years. Day after day 40 units are needed in the market. Market share is 10 % in the beginning, so 4 units per day are shipped. Customer order rate (COR) is the same but increases to 28 units in the end. The hidden assumption is that only other suppliers go bankrupt. Shipment rate (SR) is 400 units at the first day but decreases rapidly to 28 units/day approaching equilibrium with COR.

In the finished inventory (FI) the firm has 12000 units at its start-up. It is astonishing why it produce at all. If it ships out 4 units per day according to customer order rate (COR) it has enough to do over many years selling that really large inventory – without any need of producing. In the light of this starting condition the behaviour in Fig. 11 is very understandable: production rate is zero within the first 400 days. The production started afterwards has the ultimate result of an much greater inventory of final products (FI): 20000 units after 5 years. Such production makes no economic sense. At the same time the logic of an economist is satisfied: He is not wondering that this firm starts with 400 workers and ends with 32. But he would not call it business dynamics.

6. Discussion and conclusions

LYNEIS has produced a sufficiently rich model description - for our attempt to bridge the gap between SD and the business economics literature, we found this to be the only one worth proceeding with. We have presented only the first results of our attempt to reproduce this model. For one building block it could be demonstrated that the model structure produces the same time behaviour with quite a different SD-software. This is not trivial considering the differences in numerical results different software packages are producing.

But the different building blocks cannot be integrated into one complex company model. The complex company model of LYNEIS exists only in the form of a DYNAMO program listening. A reproduction of that program in POWERSIM is possible. The time behaviour of its variables cannot be compared with that of the DYNAMO program because, for the latter, LYNEIS did not present simulation runs. A reproduction of a SD model consisting of 393 variables is very difficult when only represented in a computer program listing. The underlying assumptions, meanings and interpretations cannot be reconstructed to a sufficiently accurate degree.

One possible cause of the unstable – and, in the understanding of economics and accounting, unusual - results can be seen in the initial conditions of that dynamic system. But there are other reasons as well. One critical sector seems to be capital equipment. For an economist, it is a strange situation that, in a company of 400 persons, working on 400 of the 500 units of equipment, 500 units of that machinery are scrapped, and 75 units are bought at the very first day. This needs further investigation. Inventory dynamics and equipment dynamics have different time horizons in a viable firm. In business praxis and accounting, the discrete step expansion of equipment must be differently treated than the relatively continuous movement of material and parts. In the LYNEIS model, both are treated as continuous.

As a conclusion from our search for a complex dynamic model of a firm compatible with the theory of the firm and Betriebswirtschaftslehre (which is a special German scientific approach to systemize the empirical phenomena of viable firms on the base of microeconomic theory), we see interesting further directions for scientific research:

1. Investigation of all explicit and implicit model assumptions of LYNEIS in the context of the theory and typical praxis of the firm
2. Investigating the initial conditions of the LYNEIS model more systematically, comparing them with the typical conditions of a start-up firm, and the initial date of a typical firm like PORSCHE, SONY or GE at the beginning of a usual year.
3. Simulation experiments with realistic initial data and the final LYNEIS model
4. Development of a reduced company model with the following requirements;
- the core variables should have a clear definition, identical in all building blocks of the model, and this definition must have an interpretation compatible with similar definitions in economic theory (or praxis);
- the essential dynamical structures of a typical firm should be captured; and
- the time behaviour of the reduced model should be compatible with the empirical results of the business economics literature.
5. Development of a capital equipment model on the basis of economic theory capturing the discrete nature of company expansion and producing a time behaviour similar to empirical time series.

References

Albach, H.; Brandt, Th.; Konitz, A.; Schmidt, A., and Willud, E. (1994). *Dokumentation der Bonner Stichprobe - Zur Datenbank der Jahresabschlüsse deutscher Aktiengesellschaften*, 1960-1993.WZB-discussion papers, FS IV 94 - 4., Berlin.

Lyneis, M.J. (1988). *Corporate Planning and Policy Design*. Pugh-Roberts Association Inc., Cambridge.

McCullough, B.D., and Vinod, H.D. (1999). The Numerical Reliability of Econometric Software. *The Journal of Economic Literature,* 633-665.

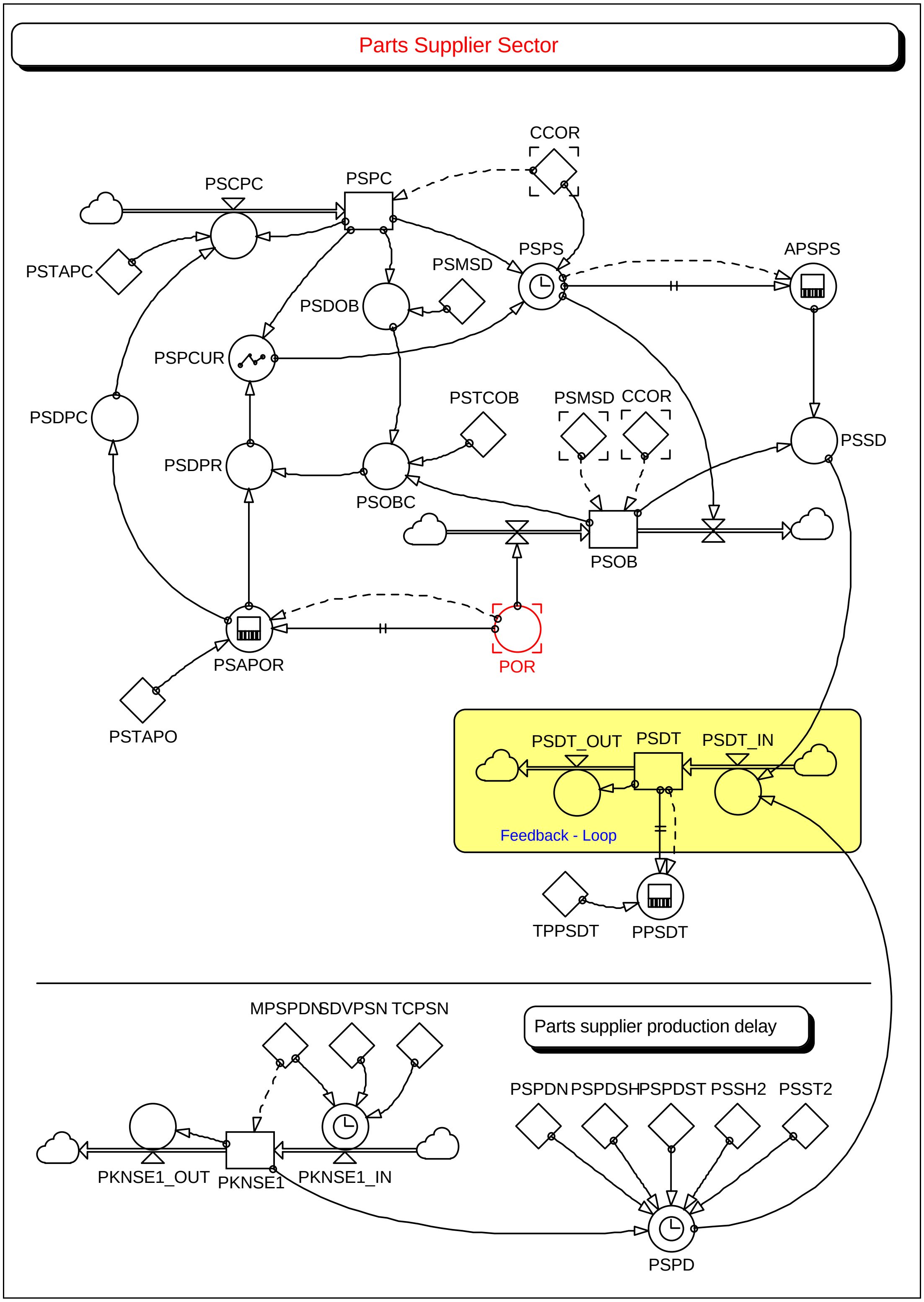
Powersim AS (1996). *Powersim 2.5 Reference Manual.* Colorcraft of Virginia, Sterling.

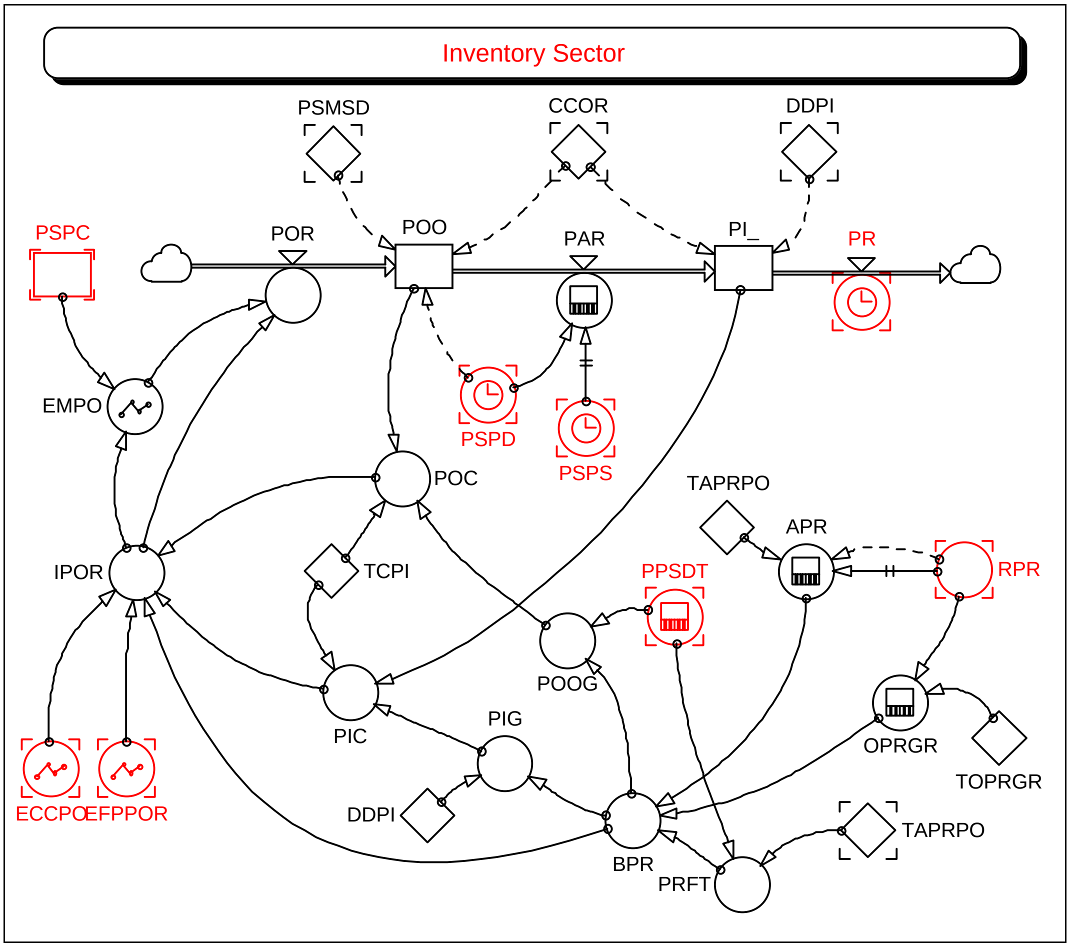
Appendix I: Equations of the two-stage inventory model in POWERSIM

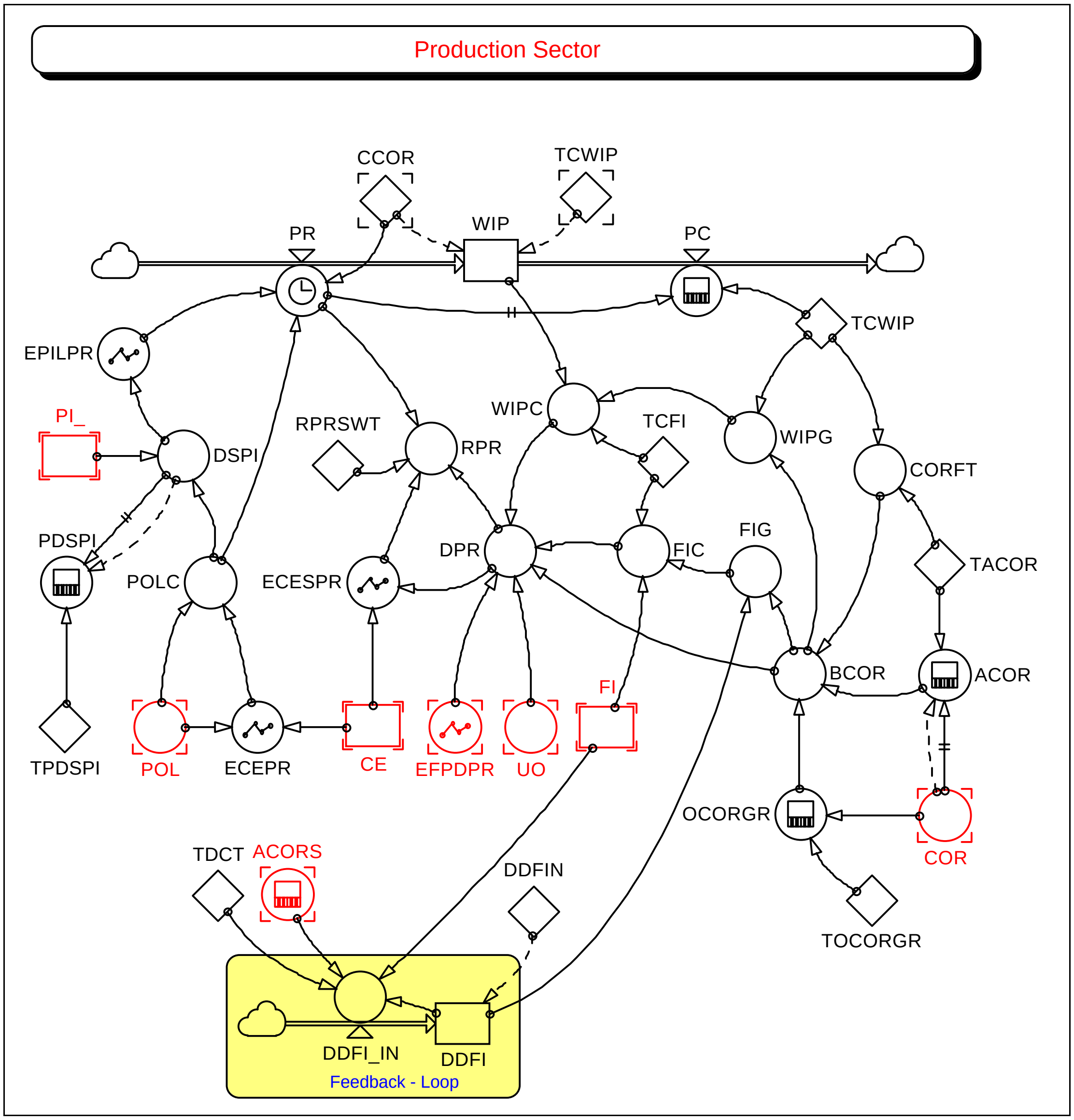
```
init    COG = 1
flow    COG = +dt*COGR
init    FI = CCOR *DDFI
flow    FI = -dt*SR
        +dt*PC
init    PI_ = CCOR * DDPI
flow    PI_ = +dt*PAR
        -dt*PR
doc     PI_ = Parts inventory
init    POO = CCOR * PSDT
flow    POO = +dt*POR
        -dt*PAR
doc     POO = Parts on order( PSPD + PSMSD ) * CCOR0
init    WIP = CCOR * TCWIP
flow    WIP = -dt*PC
        +dt*PR
aux     PAR = DELAYMTR (POR,  PSDT, 3, CCOR )
doc     PAR = Parts arrival rate
aux     PC = DELAYMTR(PR, TCWIP, 3, CCOR)
aux     POR = APR + PIC + POC
doc     POR = Parts order rate
aux     PR = ACOR + FIC + WIPC
doc     PR = Production rate
aux     SR = COR
aux     ACOR = DELAYMTR(COR,TACOR)
aux     APR = DELAYINF ( PR, TAPRPO )
doc     APR = Average production rate
aux     COGF = COG - 1
aux     COR = CCOR * ( 1 + STEP(COSH_,COST) +
ACOS * SIN(6.28*TIME/PCOS) +
ACOS2 * SIN(6.28*TIME/PCOS2) +
COGF + NORMAL(MCON, SDVCON,TCCON) )
aux     FIC = (FIG-FI) / TCFI
aux     FIG = ACOR * DDFI
aux     PIC =  ( PIG - PI_ ) / TCPI
doc     PIC = Parts inventory correction
aux     PIG = DDPI * APR
doc     PIG = Parts inventory goal
aux     POC = ( POOG - POO ) / TCPI
doc     POC = Parts on order correction
aux     POOG = APR * PSDT
doc     POOG = Parts on order goal
aux     WIPC = (WIPG - WIP) / TCFI
aux     WIPG = TCWIP * ACOR
const   COGR = 0
const   ACOS = 0
const   ACOS2 = 0
const   CCOR = 400
```

```
doc     CCOR = Constant customer order rate
const   COSH_ = 0.1
doc     COSH_ = Figure 4.2 mit 0.1 erzeugt, aber mit 0 initialisiert
const   COST = 60
const   DDFI = 30
const   DDPI = 60
doc     DDPI = Desired days parts inventory
const   MCON = 0
const   PCOS = 240
const   PCOS2 = 960
const   PSDT = 60
const   SDVCON = 0
const   TACOR = 60
const   TAPRPO = 60
doc     TAPRPO = Time to average production rate for parts ordering
const   TCCON = 10
const   TCFI = 60
const   TCPI = 240
doc     TCPI = Time to correct parts inventory
const   TCWIP = 20
```

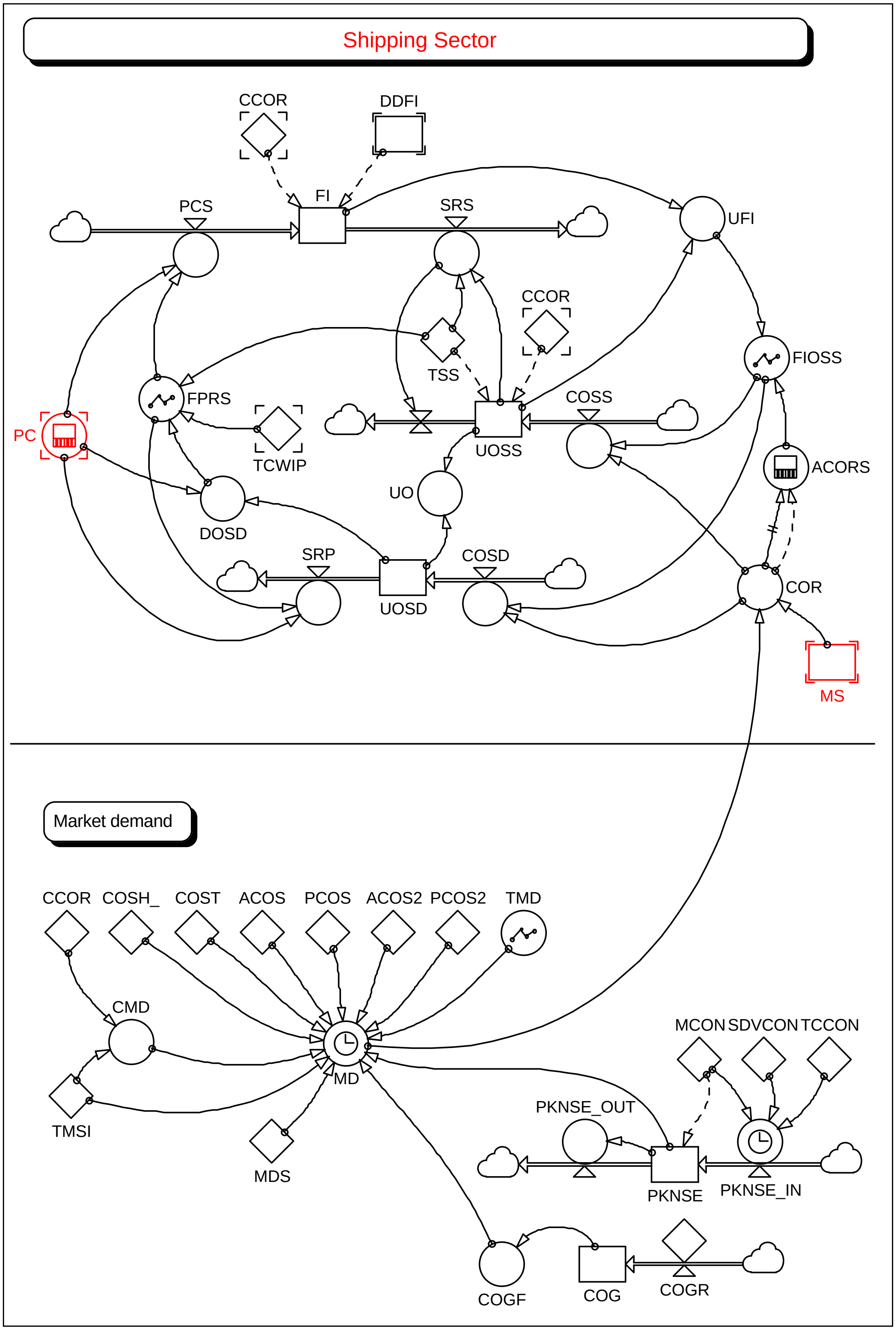
Appendix II: Structure of the final model in POWERSIM

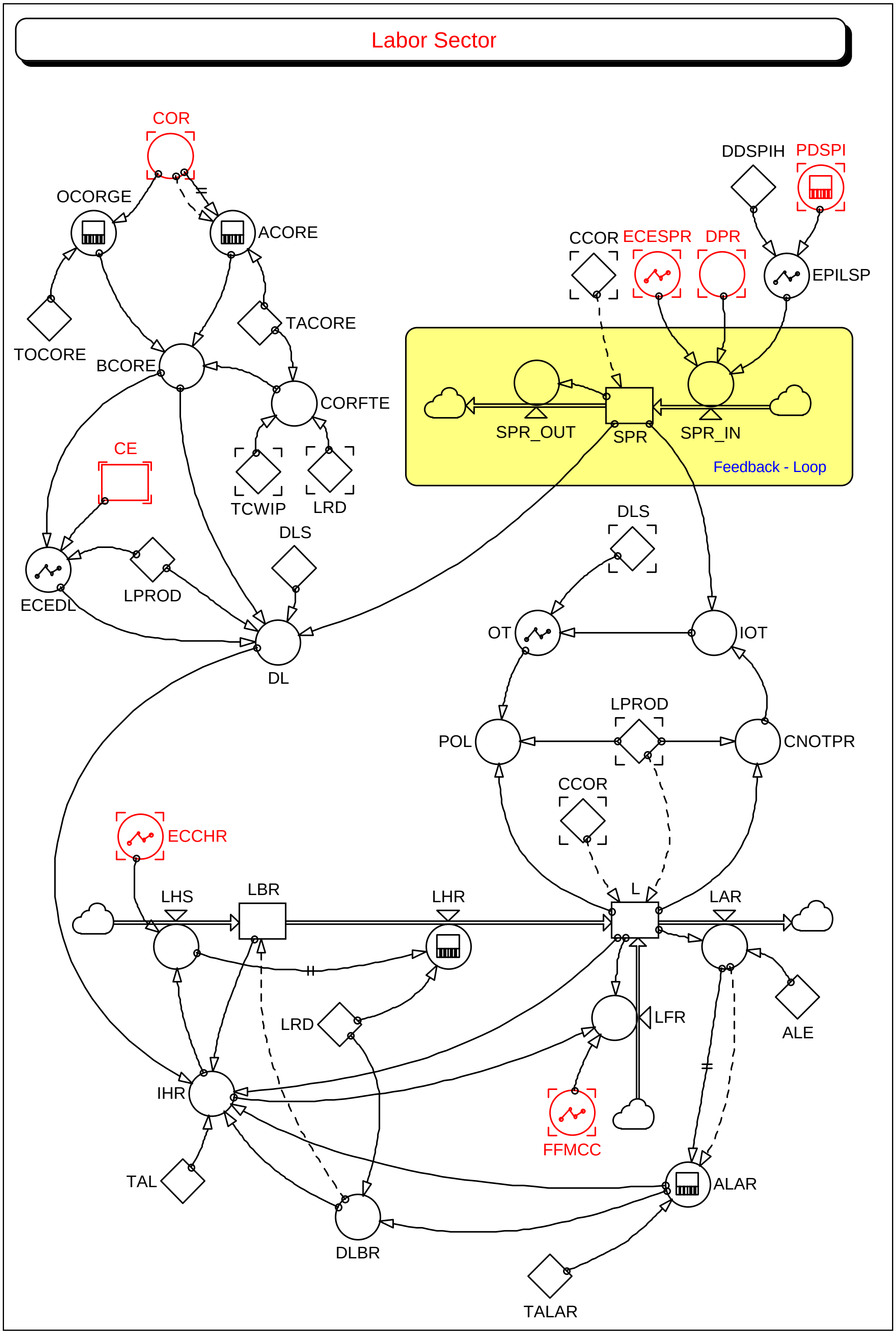


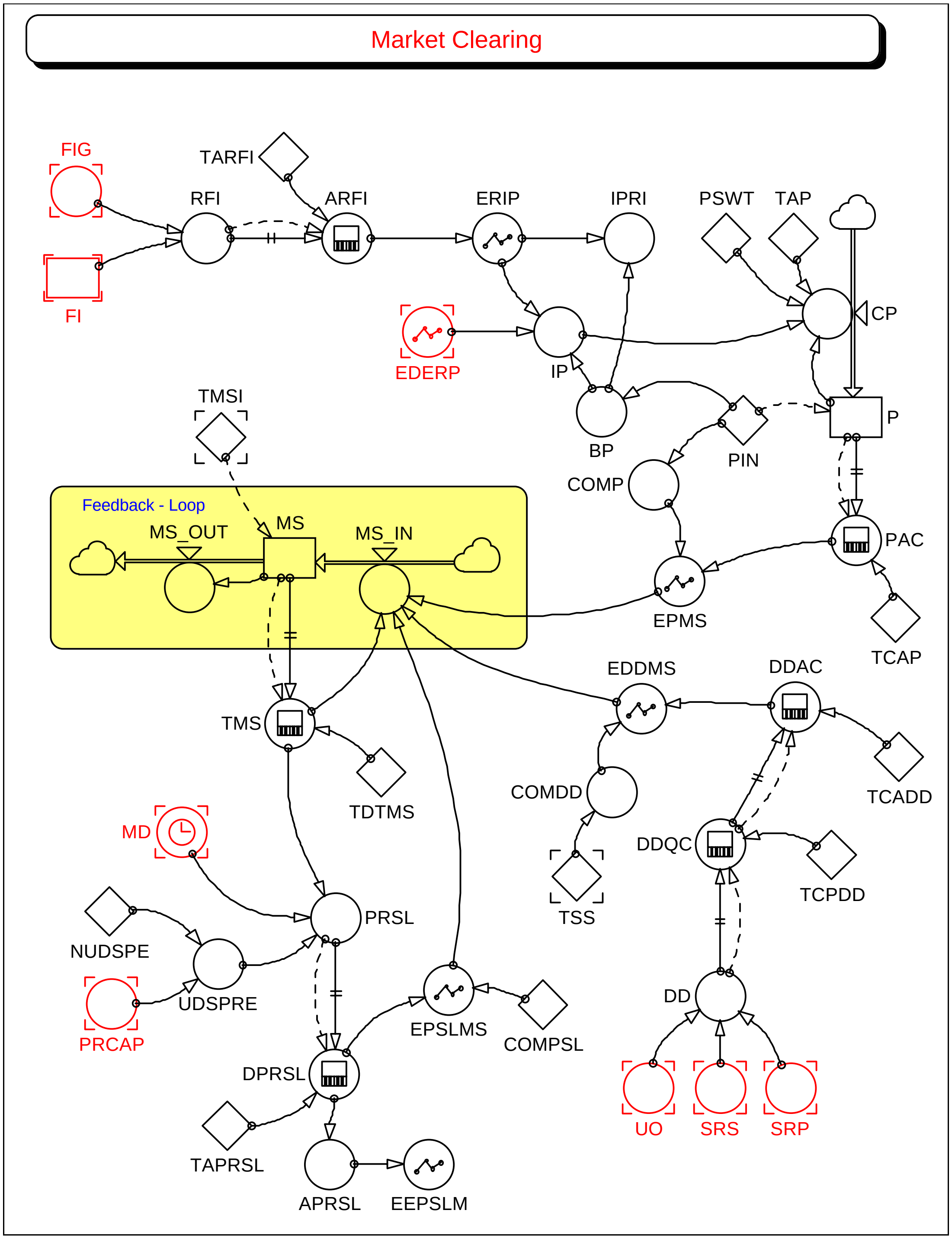

Inventory Sector
PSMSD
CCOR
DDPI
PSPC
POR
POO
PAR
PI_
PR
EMPO
PSPD
PSPS
POC
TAPRPO
APR
IPOR
TCPI
PPSDT
RPR
POOG
PIC
PIG
OPRGR
TOPRGR
DDPI
ECCPO
EFPPOR
BPR
TAPRPO
PRFT



Production Sector
CCOR
TCWIP
PR
WIP
PC
EPILPR
TCWIP
PI_
DSPI
RPRSWT
RPR
WIPC
TCFI
WIPG
CORFT
PDSPI
POLC
ECESPR
DPR
FIC
FIG
TACOR
BCOR
ACOR
TPDSPI
POL
ECEPR
CE
EFPDPR
UO
FI
OCORGR
COR
TDCT
ACORS
DDFIN
TOCORGR
DDFI_IN
DDFI
Feedback - Loop

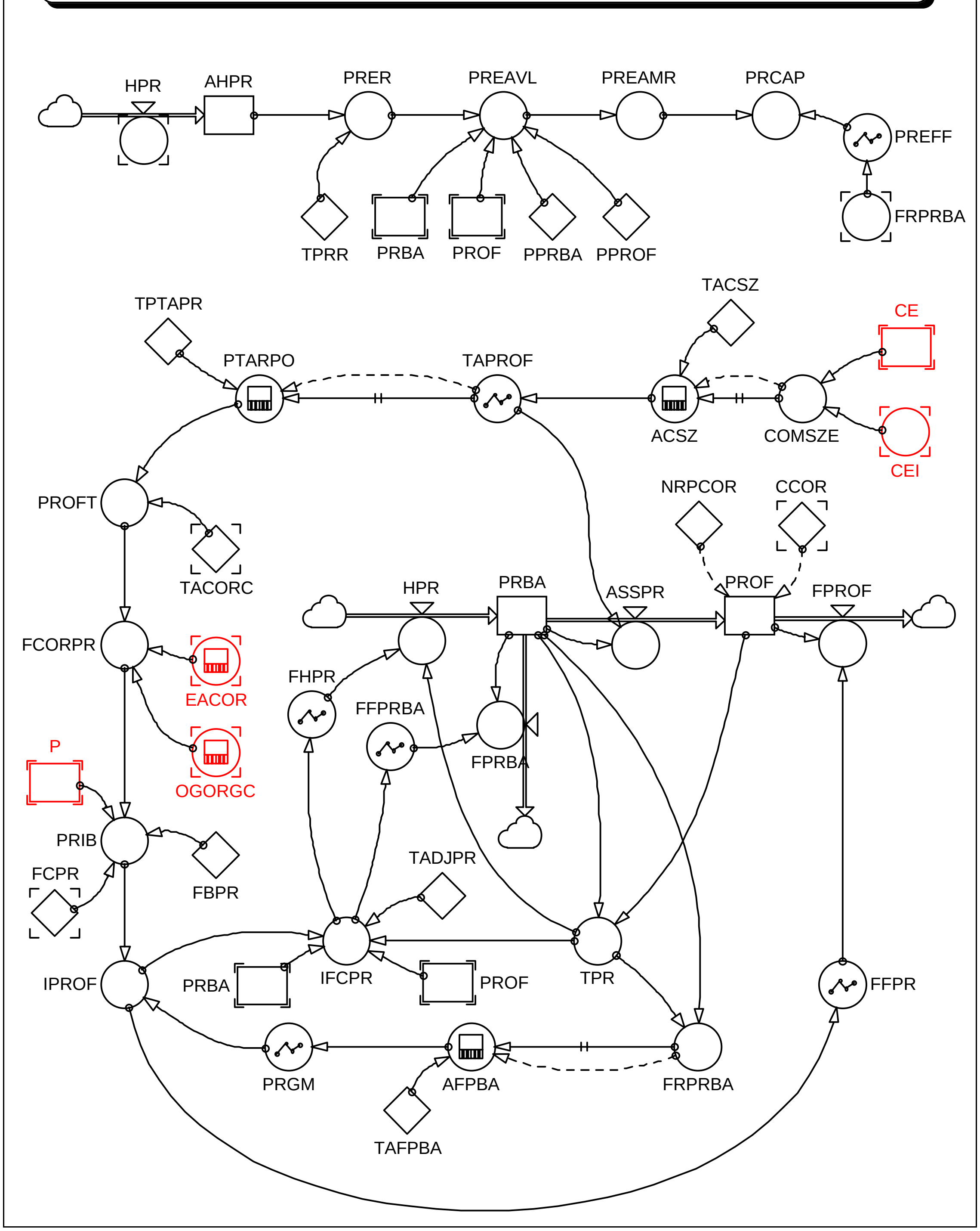

Shipping Sector
CCOR
DDFI
FI
PCS
SRS
UFI
CCOR
FIOSS
TSS
FPRS
COSS
PC
TCWIP
UOSS
ACORS
UO
DOSD
SRP
COSD
UOSD
COR
MS
Market demand
CCOR
COSH_
COST
ACOS
PCOS
ACOS2
PCOS2
TMD
CMD
MD
TMSI
MDS
MCON
SDVCON
TCCON
PKNSE_OUT
PKNSE
PKNSE_IN
COGF
COG
COGR

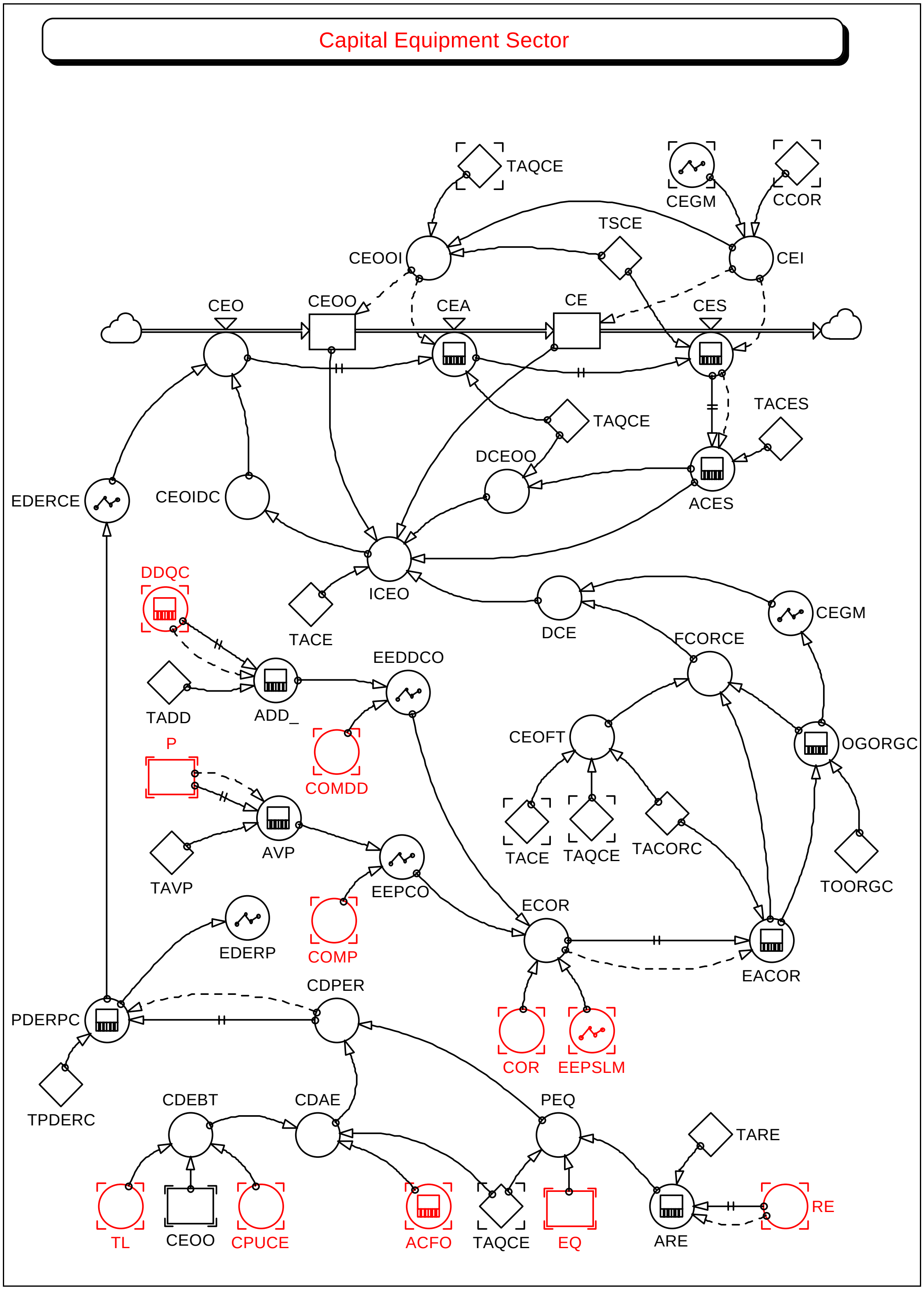

Labor Sector
COR
OCORGE
ACORE
TOCORE
BCORE
TACORE
CORFTE
CE
TCWIP
LRD
DLS
ECEDL
LPROD
DL
DDSPIH
PDSPI
CCOR
ECESPR
DPR
EPILSP
SPR_OUT
SPR
SPR_IN
Feedback - Loop
DLS
OT
IOT
LPROD
POL
CNOTPR
CCOR
ECCHR
LHS
LBR
LHR
L
LAR
LRD
LFR
ALE
IHR
FFMCC
TAL
ALAR
DLBR
TALAR

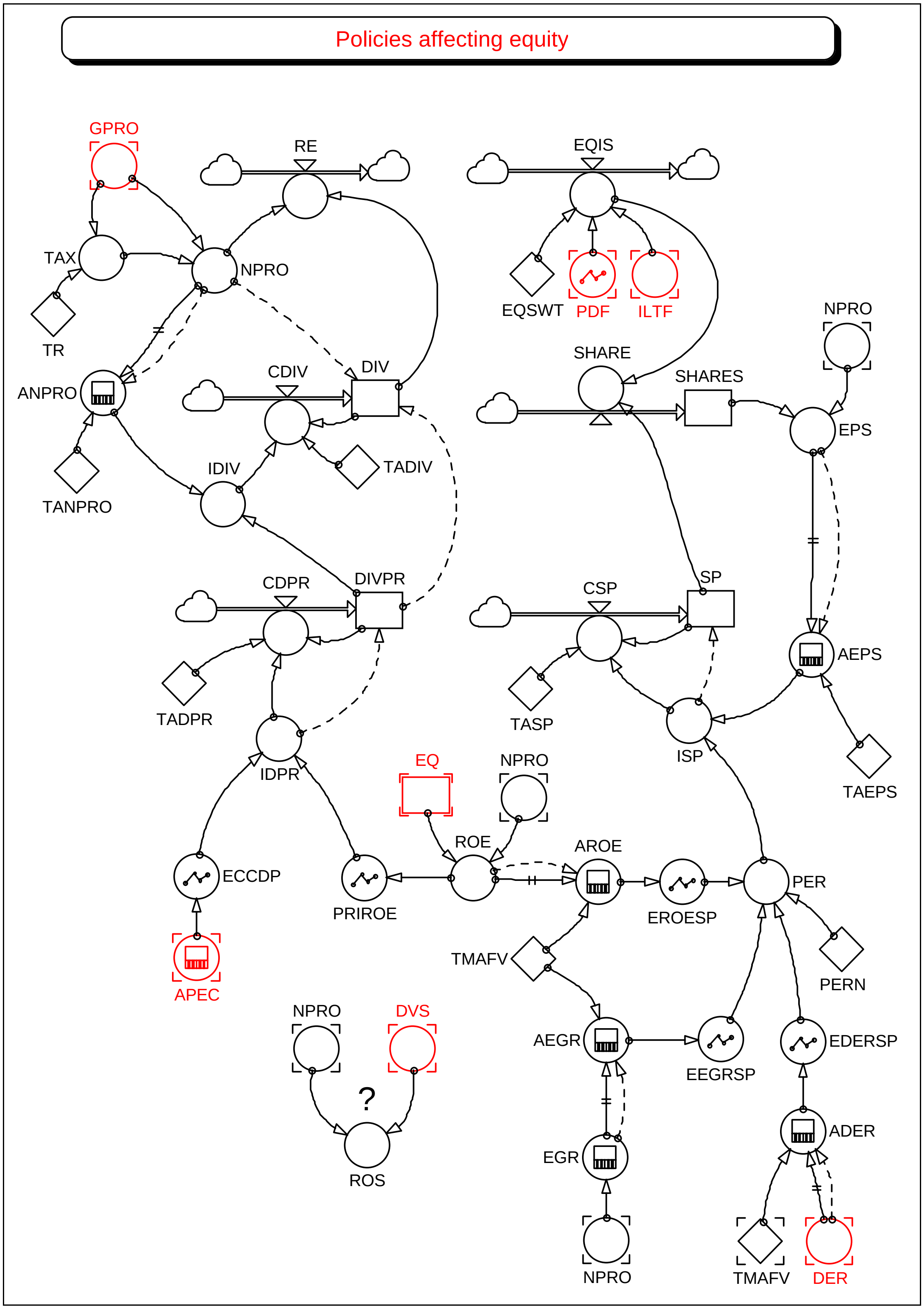


Market Clearing
FIG
TARFI
RFI
ARFI
ERIP
IPRI
PSWT
TAP
CP
FI
EDERP
IP
BP
P
TMSI
PIN
COMP
Feedback - Loop
MS
MS_OUT
MS_IN
PAC
EPMS
TCAP
EDDMS
DDAC
TMS
TDTMS
COMDD
TCADD
MD
DDQC
PRSL
TSS
TCPDD
NUDSPE
UDSPRE
DD
PRCAP
EPSLMS
COMPSL
DPRSL
UO
SRS
SRP
TAPRSL
APRSL
EEPSLM

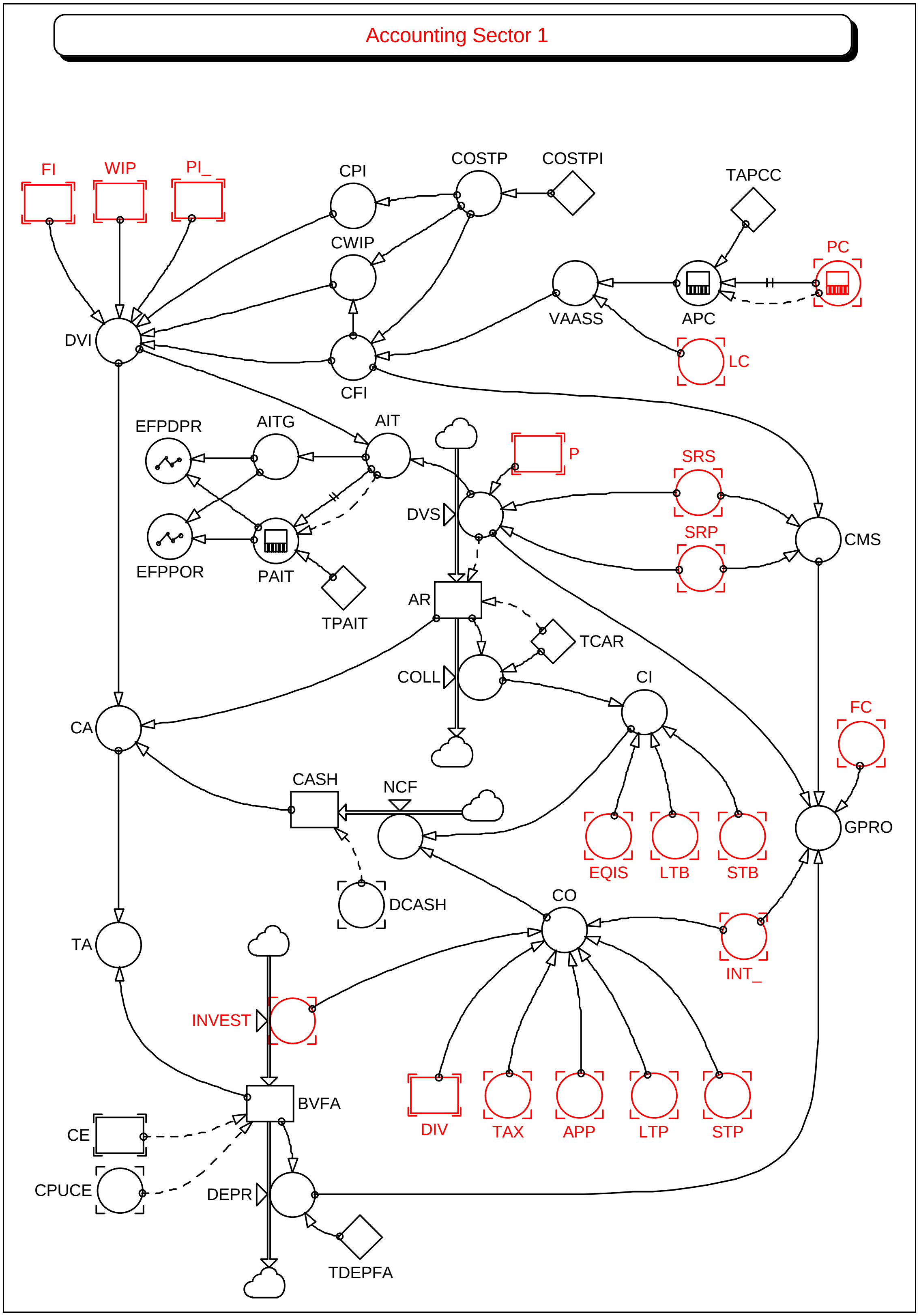
Professional Resource Sector



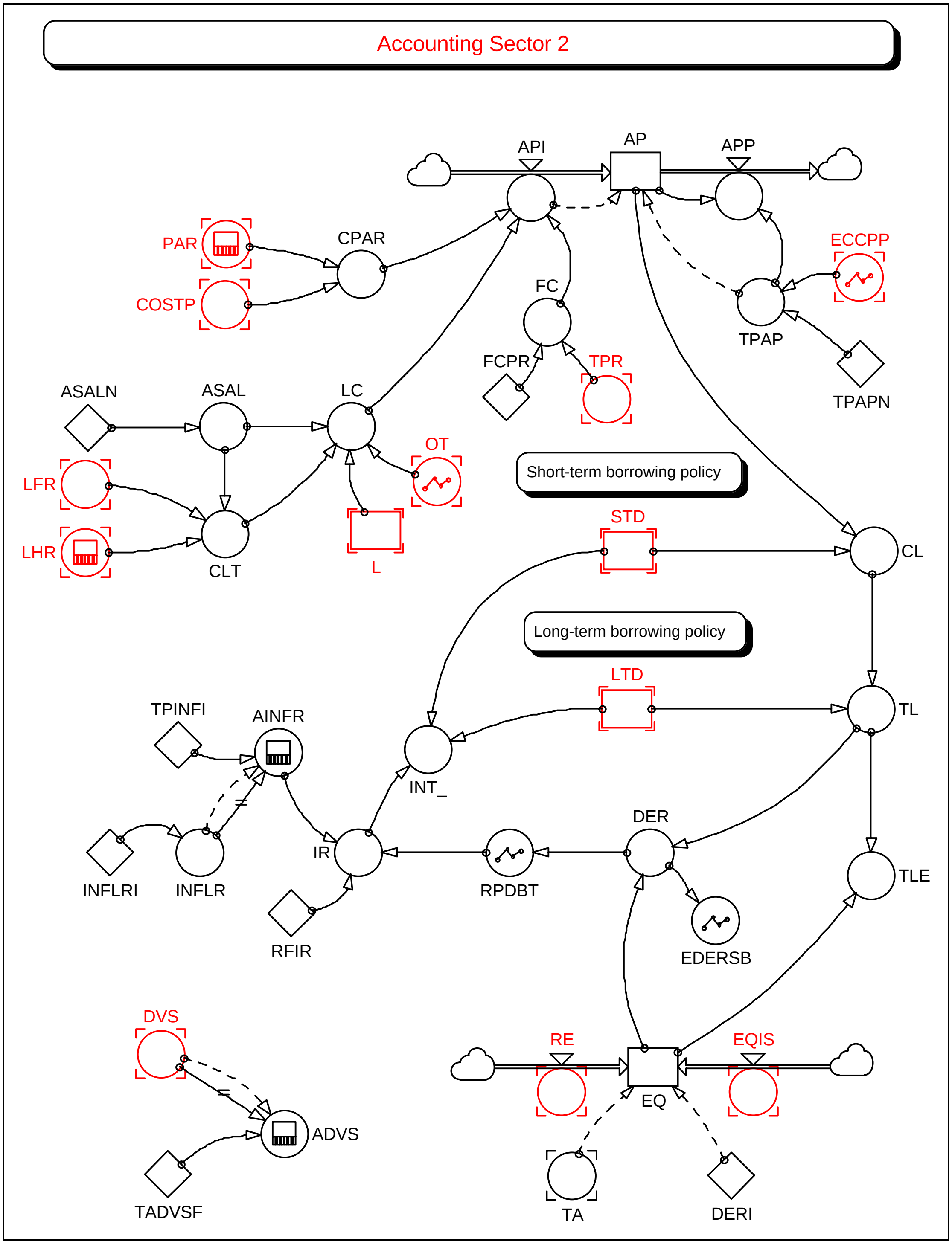

Capital Equipment Sector
TAQCE
CEGM
CCOR
TSCE
CEOOI
CEI
CEO
CEOO
CEA
CE
CES
TACES
TAQCE
DCEOO
ACES
EDERCE
CEOIDC
ICEO
DDQC
TACE
DCE
CEGM
FCORCE
TADD
ADD_
EEDDCO
COMDD
CEOFT
OGORGC
P
AVP
TAVP
EEPCO
TACE
TAQCE
TACORC
TOORGC
COMP
ECOR
EDERP
EACOR
CDPER
PDERPC
COR
EEPSLM
TPDERC
CDEBT
CDAE
PEQ
TARE
TL
CEOO
CPUCE
ACFO
TAQCE
EQ
ARE
RE



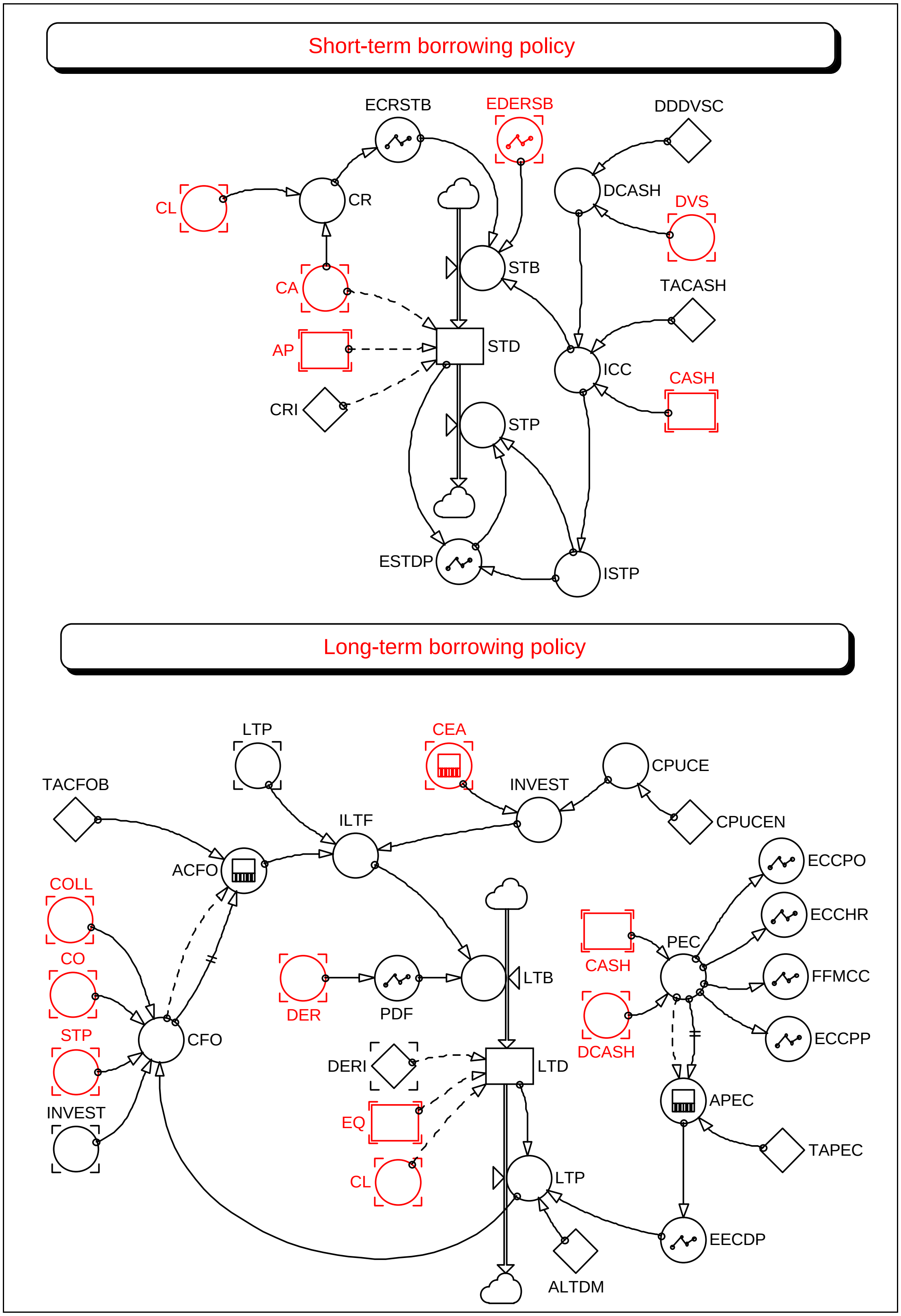
Policies affecting equity
GPRO
RE
EQIS
TAX
NPRO
TR
EQSWT
PDF
ILTF
NPRO
ANPRO
CDIV
DIV
SHARE
SHARES
EPS
TADIV
IDIV
TANPRO
CDPR
DIVPR
CSP
SP
AEPS
TADPR
TASP
IDPR
ISP
TAEPS
EQ
NPRO
ROE
AROE
ECCDP
PRIROE
EROESP
PER
TMAFV
PERN
APEC
NPRO
DVS
AEGR
EEGRSP
EDERSP
?
EGR
ADER
ROS
NPRO
TMAFV
DER



Accounting Sector 1
FI
WIP
PI_
CPI
COSTP
COSTPI
TAPCC
CWIP
PC
DVI
VAASS
APC
CFI
LC
EFPDPR
AITG
AIT
P
SRS
DVS
CMS
SRP
EFPPOR
PAIT
AR
TPAIT
TCAR
COLL
CI
CA
FC
CASH
NCF
GPRO
EQIS
LTB
STB
DCASH
CO
TA
INT_
INVEST
BVFA
DIV
TAX
APP
LTP
STP
CE
CPUCE
DEPR
TDEPFA



Accounting Sector 2
API
AP
APP
PAR
CPAR
COSTP
ECCPP
FC
TPAP
FCPR
TPR
TPAPN
ASALN
ASAL
LC
LFR
OT
Short-term borrowing policy
LHR
CLT
L
STD
CL
Long-term borrowing policy
LTD
TPINFI
AINFR
TL
INT_
DER
IR
INFLRI
INFLR
RPDBT
TLE
RFIR
EDERSB
DVS
RE
EQIS
ADVS
EQ
TADVSF
TA
DERI


Short-term borrowing policy
ECRSTB
EDERSB
DDDVSC
CL
CR
DCASH
DVS
STB
CA
TACASH
AP
STD
ICC
CASH
CRI
STP
ESTDP
ISTP
Long-term borrowing policy
LTP
CEA
TACFOB
INVEST
CPUCE
ILTF
CPUCEN
ACFO
ECCPO
COLL
ECCHR
CASH
PEC
LTB
DER
PDF
FFMCC
CO
DCASH
ECCPP
STP
CFO
DERI
LTD
APEC
EQ
INVEST
TAPEC
CL
LTP
EECDP
ALTDM

Appendix III: Equations of the final model in POWERSIM

init AHPR = 0
flow AHPR = +dt*HPR
doc AHPR = Average hiring of professionals
init AP = TPAP * API
flow AP = +dt*API
-dt*APP
doc AP = Accounts payable
init AR = TCAR * DVS
flow AR = +dt*DVS
-dt*COLL
doc AR = Accounts receivable
init BVFA = CE * CPUCE
flow BVFA = -dt*DEPR
+dt*INVEST
doc BVFA = Book value of fixed assets
init CASH = DCASH
flow CASH = +dt*NCF
doc CASH = Cash
init CE = CEI
flow CE = +dt*CEA
-dt*CES
doc CE = Capital equipment
init CEOO = CEOOI
flow CEOO = +dt*CEO
-dt*CEA
doc CEOO = Capital equipment on order
init COG = 1
flow COG = +dt*COGR
doc COG = Customer orders growth
init DDFI = DDFIN
flow DDFI = +dt*DDFI_IN
doc DDFI = Desired days finished inventory
init DIV = DIVPR * NPRO
flow DIV = +dt*CDIV
doc DIV = Dividends
init DIVPR = IDPR
flow DIVPR = +dt*CDPR
doc DIVPR = Dividend payout ratio
init EQ = TA / (1+DERI)
flow EQ = +dt*EQIS
+dt*RE
doc EQ = Equity
init FI = CCOR * DDFI
flow FI = +dt*PCS
-dt*SRS
doc FI = Finished product inventory
Fertigerzeugnisse Ist
init L = CCOR / LPROD

```
flow    L = +dt*LHR
        -dt*LAR
        +dt*LFR
doc     L = Labor
init    LBR = DLBR
flow    LBR = -dt*LHR
        +dt*LHS
doc     LBR = Labor being recruited
init    LTD = DERI * EQ - CL
flow    LTD = +dt*LTB
        -dt*LTP
doc     LTD = Long-term debt
init    MS = TMSI
flow    MS = -dt*MS_OUT
        +dt*MS_IN
doc     MS = Market share
init    P = PIN
flow    P = +dt*CP
doc     P = Price
init    PI_ = CCOR * DDPI
flow    PI_ = -dt*PR
        +dt*PAR
doc     PI_ = Parts inventory
init    PKNSE = MCON
flow    PKNSE = +dt*PKNSE_IN
        -dt*PKNSE_OUT
doc     PKNSE = Pink (correlated) noise variation
init    PKNSE1 = MPSPDN
flow    PKNSE1 = -dt*PKNSE1_OUT
        +dt*PKNSE1_IN
doc     PKNSE1 = Pink (correlated) noise variation
init    POO = ( PSPD + PSMSD ) * CCOR
flow    POO = +dt*POR
        -dt*PAR
doc     POO = Parts on order( PSPD + PSMSD ) * CCOR0
init    PRBA = 0
flow    PRBA = -dt*FPRBA
        +dt*HPR
        -dt*ASSPR
doc     PRBA = Productivity being assimilated
init    PROF = CCOR * NRPCOR
flow    PROF = -dt*FPROF
        +dt*ASSPR
doc     PROF = Professionals
init    PSDT = 0
flow    PSDT = -dt*PSDT_OUT
        +dt*PSDT_IN
doc     PSDT = Parts supplier delivery time
init    PSOB = CCOR * PSMSD
flow    PSOB = +dt*POR
```

```
        -dt*PSPS
doc     PSOB = Parts supplier order backlog
init    PSPC = CCOR
flow    PSPC = +dt*PSCPC
doc     PSPC = Parts supplier production capacity
init    SHARES = 100000
flow    SHARES = +dt*SHARE
doc     SHARES = Shares
init    SP = ISP
flow    SP = +dt*CSP
doc     SP = Stock price
init    SPR = CCOR
flow    SPR = -dt*SPR_OUT
        +dt*SPR_IN
doc     SPR = Scheduled production rate
init    STD = (CA / CRI) - AP
flow    STD = -dt*STP
        +dt*STB
doc     STD = Short-term debt
init    UOSD = 0
flow    UOSD = +dt*COSD
        -dt*SRP
doc     UOSD = Unfilled orders to be shipped direct
init    UOSS = TSS * CCOR
flow    UOSS = +dt*COSS
        -dt*SRS
doc     UOSS = Unfilled orders to be shipped from stock
init    WIP = CCOR * TCWIP
flow    WIP = +dt*PR
        -dt*PC
doc     WIP = Work in process
aux     API = CPAR + FC + LC
doc     API = Accounts payable increases
aux     APP = AP DIVZ0 TPAP
doc     APP = Accounts payable payments
aux     ASSPR = PRBA / TAPROF
doc     ASSPR = Assimilation of professionals
aux     CDIV = ( IDIV - DIV ) / TADIV
doc     CDIV = Change in dividends
aux     CDPR = ( IDPR - DIVPR ) / TADPR
doc     CDPR = Change in dividend payout ratio
aux     CEA = DELAYINF( CEO, TAQCE, 3, CEOOI )
doc     CEA = Capital equipment arrivals
aux     CEO = CEOIDC * EDERCE
doc     CEO = capital equipment orders
aux     CES = DELAYINF ( CEA, TSCE, 3, CEI )
doc     CES = Capital equipment scrappage
aux     COLL = AR / TCAR
doc     COLL = Collections
aux     COSD = COR * ( 1 - FIOSS )
```

doc COSD = Customer orders to be shipped direct
aux COSS = COR * FIOSS
doc COSS = Customer orders to be shipped from stock
aux CP = PSWT * (IP - P) / TAP
doc CP = Change in price
aux CSP = (ISP - SP) / TASP
doc CSP = Change in stock price
aux DDFI_IN = ((FI DIVZ0 ACORS) - DDFI) / TDCT
aux DEPR = BVFA / TDEPFA
doc DEPR = Depreciation
aux DVS = P * (SRP + SRS)
doc DVS = Dollar value sales
aux EQIS = ILTF * (1 - PDF) * EQSWT
doc EQIS = Equity issue
aux FPRBA = PRBA * FFPRBA
doc FPRBA = Fractional firing of professionals being assimilated
aux FPROF = PROF * FFPR
doc FPROF = Firing of professionals
aux HPR = TPR * FHPR
doc HPR = Hiring of professionals
aux INVEST = CEA * CPUCE
doc INVEST = Investment
aux LAR = L / ALE
doc LAR = Labor attrition rate
aux LFR = IHR - FFMCC * L / 12
doc LFR = Labor-firing rate
aux LHR = DELAYMTR(LHS, LRD, 3, 0)
doc LHR = Labor-hiring rate
aux LHS = MAX (0, IHR) * ECCHR
doc LHS = Labor-hiring starts
aux LTB = ILTF * PDF
doc LTB = Long-term borrowing
aux LTP = (LTD DIVZ0 ALTDM) * EECDP
doc LTP = Long-term payments
aux MS_IN = TMS * EDDMS * EPMS * EPSLMS
aux MS_OUT = MS
aux NCF = CI - CO
doc NCF = Net cash flow
aux PAR = DELAYMTR (PSPS, PSPD, 3, 0)
doc PAR = Parts arrival rate
aux PC = DELAYINF (PR, TCWIP, 3, 0)
doc PC = Production completions
aux PCS = (1 - FPRS) * PC
doc PCS = Production completion stocked
aux PKNSE_IN = (TIME / TCCON) * (SDVCON * SQRT(24 * TCCON / TIME) * 0.1) + MCON
doc PKNSE_IN = statt 1 muss NOISE modelliert werden
aux PKNSE_OUT = PKNSE
aux PKNSE1_IN = (TIME / TCPSN) * (SDVPSN * SQRT(24 * TCPSN / TIME) * 0.1) + MPSPDN

aux PKNSE1_OUT = PKNSE1
aux POR = EMPO * IPOR
doc POR = Parts order rate
aux PR = IF (TIME=0, CCOR, POLC * EPILPR)
doc PR = Production rate
aux PSCPC = (PSDPC - PSPC) / PSTAPC
doc PSCPC = Parts supplier change in production capacity
aux PSDT_IN = PSPD + PSSD
aux PSDT_OUT = PSDT
aux PSPS = IF (TIME=0, CCOR, PSPC * PSPCUR)
doc PSPS = Parts supplier production starts
aux RE = NPRO - DIV
doc RE = Retained earnings
aux SHARE = EQIS DIVZ0 SP
aux SPR_IN = IF (DPR * EPILSP * ECESPR<0, 0, DPR * EPILSP * ECESPR)
aux SPR_OUT = SPR
aux SRP = FPRS * PC
doc SRP = Shipment rate from production
aux SRS = UOSS / TSS
doc SRS = Shipment rate from stock
aux STB = MAX (0, ICC) * ECRSTB + EDERSB
doc STB = Short-term borrowing
aux STP = ISTP * ESTDP
doc STP = Short-term payments
aux ACES = DELAYINF (CES, TACES)
doc ACES = Average capital equipment scrappage
aux ACFO = DELAYINF(CFO, TACFOB)
doc ACFO = Average cash flow from operations
aux ACOR = DELAYINF (COR, TACOR)
doc ACOR = Average customer order rate
aux ACORE = DELAYINF (COR, TACORE)
doc ACORE = Average customer order rate for employment
aux ACORS = DELAYINF(COR, 20)
doc ACORS = Average customer order rate for shipping
aux ACSZ = DELAYINF (COMSZE, TACSZ)
doc ACSZ = Average company size
aux ADD_ = DELAYINF (DDQC, TADD)
doc ADD_ = Average delivery delay
aux ADER = DELAYINF (DER, TMAFV)
doc ADER = Average debt-equity ratio
aux ADVS = DELAYINF(DVS, TADVSF)
doc ADVS = Average dollar value of sales
aux AEGR = DELAYINF (EGR, TMAFV)
doc AEGR = Average earnings growth rate
aux AEPS = DELAYINF (EPS, TAEPS)
doc AEPS = average earnings per share
aux AFPBA = DELAYINF (FRPRBA, TAFPBA)
doc AFPBA = Average fraction of professionals being assimilated
aux AINFR = DELAYINF (INFLR, TPINFI)
doc AINFR = Average inflation rate

aux AIT = DVS DIVZ0 DVI
doc AIT = Annual inventory turns
aux AITG = AIT
doc AITG = Annual inventory turns goal
aux ALAR = DELAYINF (LAR, TALAR)
doc ALAR = Average labor attrition rate
aux ANPRO = DELAYINF (NPRO, TANPRO)
doc ANPRO = Average net profits
aux APC = DELAYINF (PC, TAPCC)
doc APC = Units added in assembly
aux APEC = DELAYINF (PEC, TAPEC)
doc APEC = Average percent excess cash
aux APR = DELAYINF (RPR, TAPRPO)
doc APR = Average production rate
aux APRSL = DPRSL
doc APRSL = Average professional service level
aux APSPS = DELAYINF (PSPS, 20)
doc APSPS = Average parts supplier production starts
aux ARE = DELAYINF (RE, TARE)
doc ARE = Average retained earnings
aux ARFI = DELAYINF (RFI, TARFI)
doc ARFI = Average ratio of finished inventory
aux AROE = DELAYINF (ROE, TMAFV)
doc AROE = Average return of equity
aux ASAL = ASALN
doc ASAL = Average salary
aux AVP = DELAYINF(P, TAVP)
doc AVP = Average price
aux BCOR = (1 + CORFT * OCORGR) * ACOR
doc BCOR = Base customer order rate
aux BCORE = (1 + CORFTE * OCORGE) * ACORE
doc BCORE = Base customer order rate for employment
aux BP = PIN
doc BP = BAse price
aux BPR = (1 + PRFT * OPRGR) * APR
doc BPR = Based production rate
aux CA = AR + CASH + DVI
doc CA = Current assets
aux CDAE = CDEBT - TAQCE * ACFO
doc CDAE = Committed debt adjusted for equity
aux CDEBT = TL + CEOO * CPUCE
doc CDEBT = Committed debt
aux CDPER = IF (PEQ = 0, 0, CDAE / PEQ)
doc CDPER = Committed debt projected equity ratio
aux CEGM = GRAPH(240 * OGORGC,0,0.25,[-0.2,-0.15,-
0.1,0,0.1,0.15,0.2,0.225,0.25"Min:-1;Max:1"])
doc CEGM = Capital equipment growth margin
aux CEI = CCOR * (1 + CEGM)
doc CEI = Capital equipment, initial
aux CEOFT = TACORC + TAQCE + TACE

doc CEOFT = Capital equipment orders forecasting time
aux CEOIDC = MAX (0, ICEO)
doc CEOIDC = Capital equipment orders indicated by demand conditions
aux CEOOI = (CEI / TSCE) * TAQCE
doc CEOOI = Capital equipment on order, initial
aux CFI = COSTP + VAASS
doc CFI = Cost of finished inventory
aux CFO = COLL - CO + INVEST + STP + LTP
doc CFO = Cash flow from operation
aux CI = COLL + STB + LTB + EQIS
doc CI = Cash inflows
aux CL = AP + STD
doc CL = Current liabilities
aux CLT = 6 * ASAL * (LHR + LFR)
doc CLT = Cost of labor turnover
aux CMD = CCOR * TMSI
doc CMD = Constant market demand
aux CMS = CFI * (SRS + SRP)
doc CMS = Cost of material shipped
aux CNOTPR = L * LPROD
doc CNOTPR = Current no-overtime production rate
aux CO = MAX (0, APP + STP + LTP + INT_ + DIV + TAX + INVEST)
doc CO = Cash outflows
aux COGF = COG - 1
doc COGF = Costumer orders growth factor
aux COMDD = TSS
doc COMDD = Competitor delivery delay
=TSS
aux COMP = PIN
doc COMP = Competitor price
aux COMSZE = CE / CEI
doc COMSZE = Company size
aux COR = MD * MS
doc COR = Customer order rate
aux CORFT = TACOR + TCWIP
doc CORFT = Customer order rate forecastime time
aux CORFTE = TACORE + TCWIP + LRD
doc CORFTE = Customer order rate forecasting time for employment
aux COSTP = COSTPI
doc COSTP = Cost of parts
aux CPAR = PAR * COSTP
doc CPAR = Cost of parts arrival rate
aux CPI = COSTP
doc CPI = Cost of parts inventory
aux CPUCE = CPUCEN
doc CPUCE = Cost per unit of capital equipment
aux CR = CA DIVZ0 CL
doc CR = Current ratio
aux CWIP = 0.5 * COSTP + 0.5 * CFI
doc CWIP = Cost of work in process

aux DCASH = DDDVSC * DVS
doc DCASH = Desired cash
aux DCE = (1 + CEGM) * FCORCE
doc DCE = Desired capital equipment
aux DCEOO = TAQCE * ACES
doc DCEOO = Desired capital equipment on order
aux DD = UO DIVZ0 (SRS + SRP)
doc DD = Delivery delay
aux DDAC = DELAYINF (DDQC, TCADD)
doc DDAC = Delivery delay acted on by customers
aux DDQC = DELAYINF (DD, TCPDD)
doc DDQC = Delivery delay quoted by company
aux DER = TL DIVZ0 EQ
doc DER = Debt-equity ratio
aux DL = (DLS * SPR + (1 - DLS) * BCORE * ECEDL) / LPROD
doc DL = Desired labor
aux DLBR = ALAR * LRD
doc DLBR = Desired labor being recruited
aux DOSD = UOSD DIVZ0 PC
doc DOSD = Days of orders production rate specified
aux DPR = (BCOR + FIC + WIPC + UO) * EFPDPR
doc DPR = Desired production rate
aux DPRSL = DELAYINF (PRSL, TAPRSL)
doc DPRSL = Delayed professional service level
aux DSPI = PI_ / MAX(0.001, POLC)
doc DSPI = Days supply of parts inventory
aux DVI = CFI * FI + CWIP * WIP + CPI * PI_
doc DVI = Dollar value of inventory
aux EACOR = DELAYINF (ECOR, TACORC)
doc EACOR = Estimated average customer order rate
aux ECCDP =
GRAPH(APEC,0,0.2,[0,0.1,0.5,0.9,1,1,1,1.1,1.2,1.25,1.3"Min:0;Max:1.5"])
doc ECCDP = Effect of cash condition on dividend payments
aux ECCHR = GRAPH(PEC,0,0.1,[0,0.1,0.5,0.9,1,1"Min:0;Max:1"])
doc ECCHR = Effect of cash constraints on hiring rate
aux ECCPO = GRAPH(PEC,0,0.2,[0,0.1,0.5,0.9,1,1"Min:0;Max:1"])
doc ECCPO = Effect of cash constraints on parts
aux ECCPP = GRAPH(PEC,0,0.2,[7,5,3,2,1.5,1"Min:0;Max:10"])
doc ECCPP = Effect of cash condition on payment period
aux ECEDL = GRAPH(LPROD * BCORE DIVZ0
CE,0,0.1,[1,1,0.833,0.714,0.625,0.555,0.5"Min:0;Max:1"])
doc ECEDL = Effect of capital equipment on desired labor
aux ECEPR = GRAPH(POL DIVZ0 CE,0,0.2,[1,1,1,1,0.875,0.777,0.7"Min:0;Max:1"])
doc ECEPR = Effect of capital equipment on production rate
aux ECESPR = GRAPH(DPR DIVZ0
CE,0,0.2,[1,1,1,1,0.875,0.777,0.7,0.636,0.58,0.534,0.5,0.467"Min:0;Max:1"])
doc ECESPR = Effect on capital equipment on scheduled production rate
aux ECOR = COR DIVZ0 (EEDDCO * EEPCO * EEPSLM)
doc ECOR = Estimated customer order rate
aux ECRSTB = GRAPH(CR, 0, 0.5, [0,0.4,0.7,0.9,1,1,1"Min:0;Max:1"])

doc	ECRSTB = Effect of current ratio on short-term borrowing
aux	EDDMS = GRAPH(DDAC / COMDD,0,0.25,[1,1,1,1,1,0.95,0.85,0.7,0.5,0.35,0.25,0.15,0.1,0.05,0,0,0"Min:0;Max:1"])
doc	EDDMS = Effect of delivery delay on market share
aux	EDERCE = GRAPH(PDERPC,0,0.25,[1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1"Min:0;Max:1"])
doc	EDERCE = Effect of debt-equity ratio on capacity expansion
aux	EDERP = GRAPH(PDERPC,0,0.25,[1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1"Min:0;Max:2"])
doc	EDERP = Effect of debt-equity ratio on price
aux	EDERSB = GRAPH(DER,0,0.25,[1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1"Min:0;Max:4"])
doc	EDERSB = Effect of debt-equity ratio on short-term borrowing
aux	EDERSP = GRAPH(ADER,0,0.25,[0.9,0.95,1,0.95,0.9,0.85,0.8,0.75,0.7"Min:0;Max:1"])
doc	EDERSP = Effect of debt-equity ratio on stock price
aux	EECDP = GRAPH(APEC,0,0.5,[1,1.05,1.15,1.25,1.35,1.45,1.5"Min:1;Max:1.5"])
doc	EECDP = Effect of excess cash on debt payments
aux	EEDDCO = GRAPH(ADD_ / COMDD,0,0.25,[1,1,1,1,1,0.95,0.85,0.7,0.5,0.35,0.25,0.15,0.1,0.05,0.025,0"Min:0;Max:1"])
doc	EEDDCO = Estimated effect of delivery delay on customer orders
aux	EEGRSP = GRAPH(AEGR,-0.5,0.1,[0.5,0.6,0.7,0.8,0.9,1,1.1,1.2,1.25,1.275,1.3,1.3,1.3"Min:0;Max:1.5"])
doc	EEGRSP = Effect of earnings growth rate on stock price
aux	EEPCO = GRAPH(AVP / COMP,0,0.05,[1,1,1,1,1,1,1,1,1,1,1"Min:0.75;Max:1"])
doc	EEPCO = Estimated effect of price on customer orders
aux	EEPSLM = GRAPH(APRSL,0,0.05,[1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1"Min:0.75;Max:1.25"])
doc	EEPSLM = Estimated effect of professional service level on market share
aux	EFPDPR = GRAPH(PAIT DIVZ0 AITG,0,0.25,[1,1,1,1,1,1,1,1,1"Min:0;Max:1"])
doc	EFPDPR = Effect of financial pressures on desired production rate
aux	EFPPOR = GRAPH(PAIT DIVZ0 AITG,0,0.25,[1,1,1,1,1,1,1,1,1"Min:0;Max:1"])
doc	EFPPOR = Effect of financial pressure on parts order
aux	EGR = 240 * TREND (NPRO, 240, 240)
doc	EGR = Earnings growth rate
aux	EMPO = GRAPH(IPOR DIVZ0 PSPC,0,0.2,[0,0.2,0.4,0.6,0.8,1"Min:0;Max:1"])
doc	EMPO = Effect of minimum parts order
aux	EPILPR = GRAPH(DSPI,0,10,[0,0.25,0.5,0.7,0.85,0.95,1,1,1,1"Min:0;Max:1.25"])
doc	EPILPR = Effect of parts inventory level on production rate
aux	EPILSP = GRAPH(PDSPI / DDSPIH,0,0.1,[0,0.3,0.5,0.65,0.75,0.85,0.9,0.93,0.96,0.985,1"Min:0;Max:1"])
doc	EPILSP = Effect of parts inventory level on scheduled production
aux	EPMS = GRAPH(PAC / COMP,0.75,0.05,[1.6,1.4,1.25,1.15,1.05,1,0.95,0.85,0.75,0.6,0.4"Min:0;Max:2"])
doc	EPMS = Effect of price on market share
aux	EPS = (240 * NPRO) DIVZ0 SHARES
doc	EPS = Earnings per share
Gewinn je Aktie darf nicht negativ sein !
aux	EPSLMS = GRAPH(DPRSL / COMPSL,0,0.1,[0,0.05,0.1,0.15,0.25,0.35,0.5,0.7,0.85,0.95,1,1.05,1.15,1.3,1.5,1.65,1.75,1.85,1.9,1.95,2"Min:0;Max:2"])

doc EPSLMS = Effect of professional service level on market share
aux ERIP =
GRAPH(ARFI,0.5,0.1,[1.25,1.2,1.15,1.1,1.05,1,0.95,0.9,0.85,0.8,0.75"Min:0.5;Max:1.5"])
doc ERIP = Effect of relative inventory on price
aux EROESP =
GRAPH(AROE,0,0.05,[0.1,1,1.85,2.6,3.25,3.75,3.85,3.95,4,4"Min:0;Max:4"])
doc EROESP = Effect of return on equity on stock price
aux ESTDP = GRAPH(STD / MAX (0.001, ISTP
),0,0.5,[0,0.2,0.4,0.55,0.7,0.85,0.95,1,1"Min:0;Max:1"])
doc ESTDP = Effect of short-term debt on payments
aux FC = TPR * FCPR
doc FC = Fixed costs
aux FCORCE = EACOR * (1 + CEOFT * OGORGC)
doc FCORCE = Forecast customer order rate for capital equipment
aux FCORPR = EACOR * (1 + PROFT * OGORGC)
doc FCORPR = Forecast customer order rate for professionals
aux FFMCC = GRAPH(PEC,0,0.1,[0.3,0.2,0.1,0.05,0,0"Min:0;Max:1"])
doc FFMCC = Fraction fired per month because of cash
aux FFPR = GRAPH(IPROF,0,0.0005,[0.0005,0.00025,0,0,0"Min:-0.001;Max:0.001"])
doc FFPR = Fractional firing of professionals
aux FFPRBA = GRAPH(IFCPR,0,0.005,[0.00075,0.00025,0,0,0"Min:-
0.001;Max:0.001"])
doc FFPRBA = Fractional firing of professionals being assimilated
aux FHPR =
GRAPH(IFCPR,0,0.0005,[0,0,0,0.0005,0.001,0.0015,0.002,0.0025,0.003,0.0035,0.004"Min:-
0.001;Max:0.004"])
doc FHPR = Fractional hiring of professionals
aux FIC = (FIG - FI) / TCFI
doc FIC = Finisded inventory correction
Fertigerzeugnisse Korrektur
aux FIG = DDFI * BCOR
doc FIG = Finished inventory goal
Fertigerzeugnisse Soll
aux FIOSS = GRAPH(UFI /
ACORS,0,2.5,[0,0.15,0.3,0.45,0.55,0.65,0.725,0.8,0.875,0.95,1,1,1"Min:0;Max:1"])
doc FIOSS = Fraction of incoming orders to be shipped from stocked
aux FPRS = GRAPH(DOSD / (TCWIP +
TSS),0,0.2,[0,0.3,0.58,0.8,0.95,1"Min:0;Max:1"])
doc FPRS = Fraction of production rate specified
aux FRPRBA = PRBA DIVZ0 TPR
doc FRPRBA = Fraction of professionals being assimilated
aux GPRO = DVS - CMS - FC - DEPR - INT_
doc GPRO = Gross profits
aux ICC = MAX (0, (DCASH - CASH) / TACASH)
doc ICC = Indicated change in cash
aux ICEO = ACES + (DCE - CE + DCEOO - CEOO) / TACE
doc ICEO = Indicated capital equipment orders
aux IDIV = DIVPR * ANPRO
doc IDIV = Indicated dividends
aux IDPR = PRIROE * ECCDP

doc IDPR = Indicated dividend payout ratio
aux IFCPR = ((IPROF - PROF - PRBA) / TADJPR) DIVZ0 TPR
doc IFCPR = Indicated fractional change in professionals
aux IHR = ALAR + (DL - L +DLBR - LBR) / TAL
doc IHR = Indicated hiring rate
aux ILTF = MAX (0, INVEST + LTP - ACFO)
doc ILTF = Indicated long-term financing
aux INFLR = INFLRI
doc INFLR = Inflation rate
aux INT_ = IR * (LTD + STD) / 240
doc INT_ = Interest payments
aux IOT = SPR / CNOTPR
doc IOT = Indicated overtime
aux IP = BP * ERIP * EDERP
doc IP = Indicated price
aux IPOR = (BPR + PIC + POC) * EFPPOR * ECCPO
doc IPOR = Indicated parts order rate
aux IPRI = BP * ERIP
doc IPRI = Indicated price from relative inventory
aux IPROF = PRIB * (1 + PRGM)
doc IPROF = Indicated professionals
aux IR = RFIR + RPDBT + AINFR
doc IR = Interest rate
aux ISP = AEPS * PER
doc ISP = Indicated stock price
aux ISTP = (-1) * MIN(0, ICC)
doc ISTP = Indicated short-term payment
aux LC = L * ASAL + MAX(OT - 1, 0) * L * 1.5 * ASAL + CLT
doc LC = Labor costs
aux MD = (CMD * (1 + COGF)) *
(1 + STEP(COSH_, COST) + ACOS * SIN(6.28 * TIME / PCOS) +
ACOS2 * SIN(6.28 * TIME / PCOS2) + PKNSE) *
MDS + (1 - MDS) * TMD / TMSI
doc MD = Market demand
aux NPRO = GPRO - TAX
doc NPRO = Net profits
aux OCORGE = TREND (COR, TOCORE, COR)
doc OCORGE = Observed customer order rate growth for employment
aux OCORGR = TREND(COR, TOCORGR, COR)
doc OCORGR = Observed customer order rate growth rate
aux OGORGC = TREND (EACOR, TOORGC, 0.0008)
doc OGORGC = Observed customer order rate growth for capacity
aux OPRGR = TREND (RPR, TOPRGR, TOPRGR)
doc OPRGR = Observed production rate growrh rate
aux OT = GRAPH(IOT,0,0.2,[0,0.2,0.4,0.6,0.8,1,1.2,1.35,1.4"Min:0;Max:1.6"]) * (1 - DLS) + DLS
doc OT = Overtime
aux PAC = DELAYINF (P, TCAP)
doc PAC = Price acted on by customers
aux PAIT = DELAYINF (AIT, TPAIT)

doc PAIT = Perceived annual inventory turns
aux PDERPC = DELAYINF (CDPER, TPDERC)
doc PDERPC = Perceived debt-equity ratio for capacity
aux PDF = GRAPH(DER,0,0.25,[1,1,0.9,0.5,0.1,0,0,0,0"Min:0;Max:1"])
doc PDF = Percent debt financing
aux PDSPI = DELAYINF (DSPI, TPDSPI)
doc PDSPI = Perceived days supply parts inventory
aux PEC = (CASH - DCASH) DIVZ0 DCASH
doc PEC = Percent excess cash
aux PEQ = EQ + TAQCE * ARE
doc PEQ = Projected equity
aux PER = PERN * EROESP * EEGRSP * EDERSP
doc PER = Price-earnings ratio
aux PIC = (PIG - PI_) / TCPI
doc PIC = Parts inventory correction
Lager Teile Korrektur
aux PIG = DDPI * BPR
doc PIG = Parts inventory goal
Lager Teile Soll
aux POC = (POOG - POO) / TCPI
doc POC = Parts on order correction
Korrektur Bestellung
aux POL = L * LPROD * OT
doc POL = Potential output from labor
aux POLC = POL * ECEPR
doc POLC = Potential output from labor and capital
aux POOG = PPSDT * BPR
doc POOG = Parts on order goal
Bestellmenge Soll
aux PPSDT = DELAYINF (PSDT, TPPSDT)
doc PPSDT = Perceived parts supplier delivery time
aux PRCAP = PREAMR * PREFF
doc PRCAP = Professional capability
aux PREAMR = PREAVL
doc PREAMR = Professional effort allocated to marketing and research
aux PREAVL = PROF * PPROF + PRBA + PPRBA - PRER
doc PREAVL = Professional effort available
aux PREFF =
GRAPH(FRPRBA,0,0.05,[1,0.975,0.925,0.85,0.75,0.675,0.625,0.6,0.6"Min:0.4;Max:1"])
doc PREFF = Professional effeciency
aux PRER = AHPR * TPRR
doc PRER = Professional effort recruiting
aux PRFT = PPSDT + TAPRPO
doc PRFT = Production rate forecasting time
aux PRGM = GRAPH(AFPBA,0,0.05,[0,0,0,0,0,0,0,0,0"Min:0;Max:1"])
doc PRGM = Professional growth margin
aux PRIB = FBPR * FCORPR * P / FCPR
doc PRIB = Professionals indicated by budget
aux PRIROE =
GRAPH(ROE,0,0.05,[0.75,0.65,0.55,0.45,0.35,0.25,0.15,0.05,0,0"Min:0;Max:1"])

doc PRIROE = Payout ratio indicated by return on equity
aux PROFT = PTARPO + TACORC
doc PROFT = Professionals forecasting time
aux PRSL = UDSPRE DIVZ0 (MD * TMS)
doc PRSL = Professional service level
aux PSAPOR = DELAYINF (POR, PSTAPO)
doc PSAPOR = Parts supplier average parts order rate
aux PSDOB = PSMSD * PSPC
doc PSDOB = Parts supplier desired orders backlog
aux PSDPC = PSAPOR
doc PSDPC = Parts supplier desired production capacity
aux PSDPR = PSAPOR + PSOBC
doc PSDPR = Parts supplier desired production rate
aux PSOBC = (PSOB - PSDOB) / PSTCOB
doc PSOBC = Parts supplier order backlog correction
aux PSPCUR = GRAPH(
PSDPR DIVZ0 PSPC,
0,0.25,[0,0.25,0.5,0.75,1,1.15,1.25,1.3,1.3"Min:0;Max:1.5"])
doc PSPCUR = Parts supplier capacity utilization rate
aux PSPD = PSPDN * (1 + STEP(PSPDSH, PSPDST) + STEP(PSSH2, PSST2) + PKNSE1)
doc PSPD = Parts supplier production delay
aux PSSD = PSOB DIVZ0 APSPS
doc PSSD = Parts supplier scheduling delay
aux PTARPO = DELAYINF (TAPROF, TPTAPR)
doc PTARPO = Perceived time to assimilate professionals
aux RFI = IF (FIG=0, 0, FI / FIG)
doc RFI = Ratio of finished inventory
aux ROE = (240 * NPRO) DIVZ0 EQ
doc ROE = Return on equity
aux ROS = NPRO DIVZ0 DVS
doc ROS = Return on sales
aux RPDBT =
GRAPH(DER,0,0.1,[0.015,0.0175,0.02,0.0225,0.025,0.03,0.04,0.055,0.075"Min:0;Max:0.12"])
doc RPDBT = Risk premium of debt
aux RPR = (1 - RPRSWT) * PR + RPRSWT * DPR * ECESPR
doc RPR = Reference production rate
aux TA = CA + BVFA
doc TA = Total assets
aux TAPROF =
GRAPH(ACSZ,0,1,[120,120,140,170,210,260,320,370,410,440,460,480,480"Min:100;Max:500"])
doc TAPROF = Time to assimilate professionals
aux TAX = GPRO * TR
doc TAX = Taxes
aux TL = CL + LTD
doc TL = Total liabilities
aux TLE = TL + EQ
doc TLE = Total liabilities and equity

aux TMD =
GRAPH(TIME,0,1,[400,475,650,900,1250,1700,2150,2500,2750,2900,3000,2900,2750,2500
,2150,1700"Min:0;Max:3000;Zoom"])
doc TMD = Table for market demand
aux TMS = DELAYINF (MS, TDTMS)
doc TMS = Traditional market share
aux TPAP = TPAPN * ECCPP
doc TPAP = Time to pay accounts payable
aux TPR = PRBA * PROF
doc TPR = Total professionals
aux UDSPRE = NUDSPE * PRCAP
doc UDSPRE = Units per day servicable by professional effort
aux UFI = FI - UOSS
doc UFI = Uncommitted finished inventory
aux UO = UOSS + UOSD
doc UO = Unfilled orders
aux VAASS = LC DIVZ0 APC
doc VAASS = Value added in assembly
aux WIPC = (WIPG - WIP) / TCFI
doc WIPC = Work in process correction
Unfertige Erzeugnisse Korrektur
aux WIPG = TCWIP * BCOR
doc WIPG = Work in process goal
Unfertige Erzeugnisse Soll
const COGR = 0
doc COGR = Customer orders growth rate
const ACOS = 0
doc ACOS = Amplitude of costumer order sine
const ACOS2 = 0
doc ACOS2 = Amplitude of costumer order sine two
const ALE = 480
doc ALE = Average length of employment
const ALTDM = 2400
doc ALTDM = Average long-term debt maturity
const ASALN = 40
doc ASALN = Average salary initial
const CCOR = 400
doc CCOR = Constant customer order rate
const COMPSL = 1
doc COMPSL = Competitor professional service level
const COSH_ = 0
doc COSH_ = Costumer order step height
const COST = 60
doc COST = Costumer order step time
const COSTPI = 30
doc COSTPI = Cost of parts initial
const CPUCEN = 6000
doc CPUCEN = Cost per unit of capital equipment initial
const CRI = 2.5
doc CRI = Current ratio initial

const DDDVSC = 15
doc DDDVSC = Desired days dollar value of sales for cash
const DDFIN = 30
const DDPI = 60
doc DDPI = Desired days parts inventory
Verweildauer im Teilelager
const DDSPIH = 60
doc DDSPIH = Desired days supply parts inventory hiring
const DERI = 0.5
doc DERI = Debt-equity ratio initial
const DLS = 1
doc DLS = Desired labor switch
const EQSWT = 1
doc EQSWT = Equity switch
const FBPR = 0.17
const FCPR = 170
doc FCPR = Fixed costs percentage
const INFLRI = 0
doc INFLRI = Inflation rate, initial
const LPROD = 1
doc LPROD = Labor productivity
const LRD = 20
doc LRD = Labor-recruiting delay
const MCON = 0
doc MCON = Mean of costumer order noise
const MDS = 1
doc MDS = Market demand switch
const MPSPDN = 0
doc MPSPDN = Mean of parts supplier production delay noise
const NRPCOR = 0.1
doc NRPCOR = Normal ratio of professionals to customer order rate
const NUDSPE = 10
doc NUDSPE = Normal units per day servicable by professional effort
const PCOS = 240
doc PCOS = Period of costumer order sine
const PCOS2 = 960
doc PCOS2 = Period of costumer order sine two
const PERN = 10
doc PERN = Price earnings ratio, normal
const PIN = 100
doc PIN = Price, initial
const PPRBA = 0.25
doc PPRBA = Productivity of professionals being assimilated
const PPROF = 1
doc PPROF = Productivity of professionals
const PSMSD = 10
doc PSMSD = Parts supplier minimum scheduling delay
const PSPDN = 50
doc PSPDN = Parts supplier production delay normal
const PSPDSH = 0

doc PSPDSH = Parts supplier production delay STEP height
const PSPDST = 60
doc PSPDST = Parts supplier production delay STEP time
const PSSH2 = 0
doc PSSH2 = Parts supplier STEP height two
const PSST2 = 180
doc PSST2 = Parts supplier STEP time 2
const PSTAPC = 480
doc PSTAPC = Parts supplier time to adjust production capacity
const PSTAPO = 30
doc PSTAPO = Parts supplier time to average parts orders
const PSTCOB = 60
doc PSTCOB = Parts supplier time to correct order backlog
const PSWT = 0
doc PSWT = Price switch
const RFIR = 0.02
doc RFIR = Risk free interest rate
const RPRSWT = 1
doc RPRSWT = Reference production rate switch
const SDVCON = 0
doc SDVCON = Standard deviation of costumer orders noise
const SDVPSN = 0
doc SDVPSN = Standard deviation of parts supplier noise
const TACASH = 10
doc TACASH = Time to adjust cash
const TACE = 60
doc TACE = Time to adjust capital equipment
const TACES = 120
doc TACES = Time to average capital equipment scrappage
const TACFOB = 240
doc TACFOB = Time to average cash flow from operations for borrowing
const TACOR = 60
doc TACOR = Time to average costumer order rate
const TACORC = 240
doc TACORC = Time to average customer order rate for capacity
const TACORE = 60
doc TACORE = Time to average customer order ratefor employment
const TACSZ = 240
const TADD = 60
doc TADD = Time to average delivery delay
const TADIV = 120
doc TADIV = Time to adjust dividends
const TADJPR = 120
const TADPR = 120
doc TADPR = Time to adjust dividende payout ratio
const TADVSF = 480
doc TADVSF = Time to average dollar value of sales for fixed costs
const TAEPS = 240
doc TAEPS = Time to average earnings per share
const TAFPBA = 480

const TAL = 20
doc TAL = Time to adjust labor
const TALAR = 40
doc TALAR = Time to average labor attrition rate
const TANPRO = 240
doc TANPRO = Time to average net profit
const TAP = 60
doc TAP = Time to adjust price
const TAPCC = 20
doc TAPCC = Time to average production completions for costing
const TAPEC = 240
doc TAPEC = Time to average percent excess cash
const TAPRPO = 60
doc TAPRPO = Time to average production rate for parts ordering
const TAPRSL = 480
const TAQCE = 360
doc TAQCE = Time to aquire capital equipment
const TARE = 240
doc TARE = Time to average retained earnings
const TARFI = 60
doc TARFI = Time to average ratio of finished inventory
const TASP = 20
doc TASP = Time to adjust stock price
const TAVP = 60
doc TAVP = Time to average price
const TCADD = 60
doc TCADD = Time for customer to act on delivery delay
const TCAP = 60
doc TCAP = Time for customers to act on price
const TCAR = 40
doc TCAR = Time to collect accounts receivable
const TCCON = 10
doc TCCON = Time constant of costumer orders noise
const TCFI = 240
doc TCFI = Time to correct finished inventory
Zeit für Fertigerzeugnisse Korrektur
const TCPDD = 20
doc TCPDD = Time for company quoted by company
const TCPI = 240
doc TCPI = Time to correct parts inventory
Zeit für Korrektur Teilelager
const TCPSN = 10
doc TCPSN = Time constant of parts supplier noise
const TCWIP = 20
doc TCWIP = Time to complete work in progress
Zeit für Komplettierung Unfertiger Erzeugnisse
const TDCT = 50000
doc TDCT = Time to develop comapny traditions
const TDEPFA = 2400
doc TDEPFA = Time to depreciate fixed assets

const TDTMS = 960
doc TDTMS = Time to develop traditional market share
const TMAFV = 480
doc TMAFV = Time for market to average financial variables
const TMSI = 0.1
doc TMSI = Traditional market share initial
const TOCORE = 480
doc TOCORE = Time to observe customer order rate growth for employment
const TOCORGR = 480
doc TOCORGR = Time to observe customer order rate growth
const TOORGC = 240
doc TOORGC = Time to observe customer order rate growth for capacity
const TOPRGR = 480
doc TOPRGR = Time to observe production rate growrh rate
const TPAIT = 20
doc TPAIT = Time to perceive annual inventory turns
const TPAPN = 30
doc TPAPN = Time to pay accounts payable
const TPDERC = 60
doc TPDERC = Time to perceive debt-equity ratio for capacity
const TPDSPI = 20
doc TPDSPI = Time to perceive days supply parts inventory
const TPINFI = 240
doc TPINFI = Time to perceive inflation for interest rates
const TPPSDT = 60
doc TPPSDT = Time to perceive parts supplier delivery time
const TPRR = 0.025
doc TPRR = Time for professional recruiting
const TPTAPR = 480
doc TPTAPR = Time to perceive time assimilate professionals
const TR = 0.5
doc TR = Tax rate
const TSCE = 2400
doc TSCE = Time to scrap capital equipment
const TSS = 5
doc TSS = Time to ship from stock

---

[1] See ALBACH et. al. (1994).
[2] The equations are shown in appendix I.
[3] McCULLOUGH and VINOD (1999).