THE FACULTY OF ENGINEERING

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DOCTORAL THESIS

CONTRIBUTIONS REGARDING THE USE OF EXPERT SYSTEMS IN PLANNING AND CONTROL OF FINISHED GOODS INVENTORY MANAGEMENT

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SIBIU

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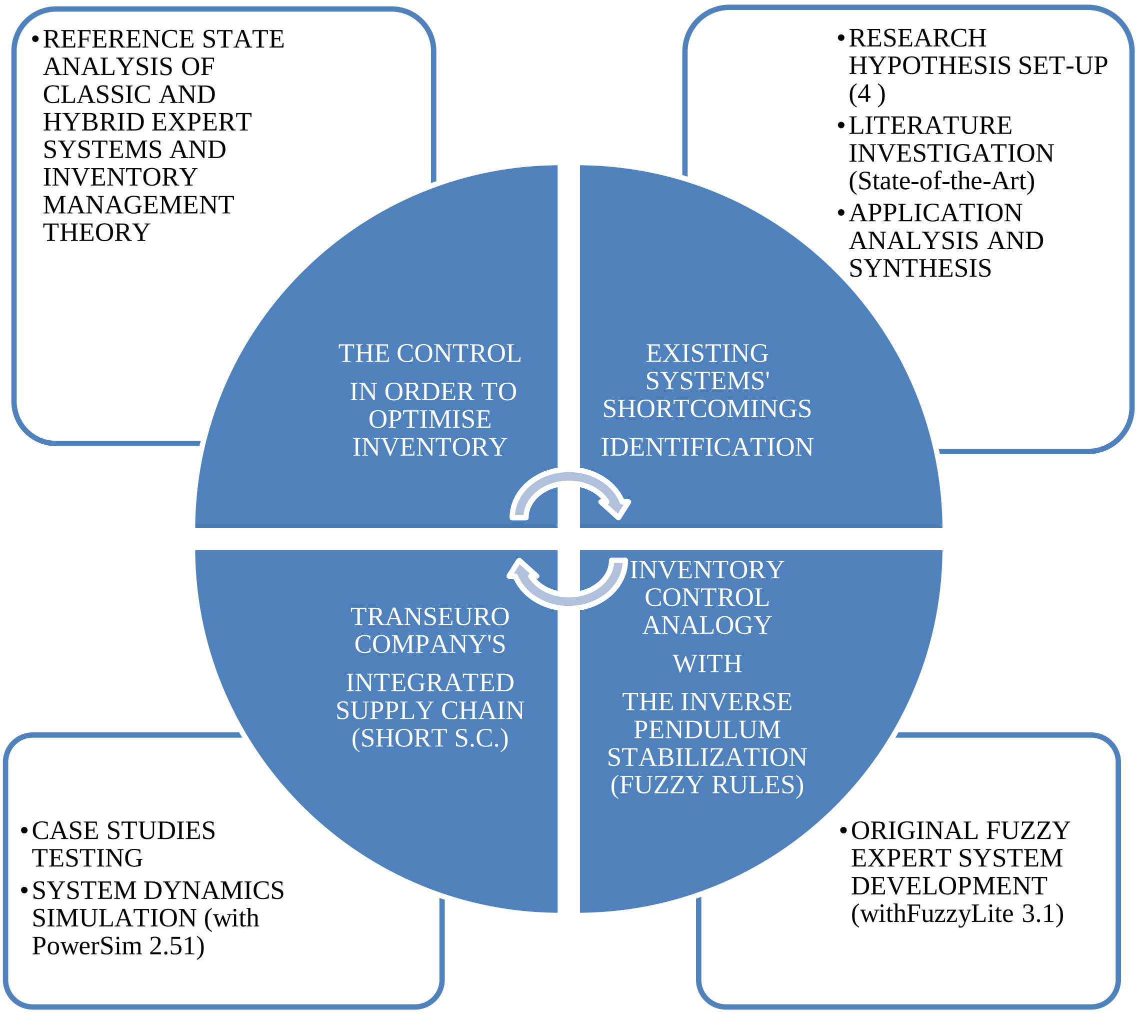
I am deeply grateful to my wife, Cristina Stoia, who - every day - was with me in the material and intellectual efforts of these three years.

Also, to my mother, brothers, brothers-in-law, my in-laws and Mrs. Florica Achim, I am indebted for moral support and their understanding.

Thesis' brief structure:

Motto: ''In order to be creative one must first gain control of the medium. One can not even begin to think about organizing a great photograph without having the skills to make it happen. In engineering, as in other creative arts, we must learn to do analysis to support our efforts in synthesis.''[1] *(Gerald J. Sussman, Cambridge)*



[1] Foreword by Gerald J. Sussman (n.d.), URL: http://www.ccs.neu.edu/home/matthias/BTLS/foreword.html [Accesat la data de 20 octombrie 2015]

CONTENTS

PART I: Reference state regarding the domain of Fuzzy Expert Systems for finished goods inventory management

The reference state's approach is from the sum of „*general, canonical and specific knowledge*'' that one considers in order to create, a special attention must pay to the canonical knowledge that ''comes from a particular school'' and therefore must be explicitly reported to the readers.[2]

1.1 Reference state of Expert Systems

The cause – effect relationship between smarter work and productivity is the main assumption of the present thesis' demarche.

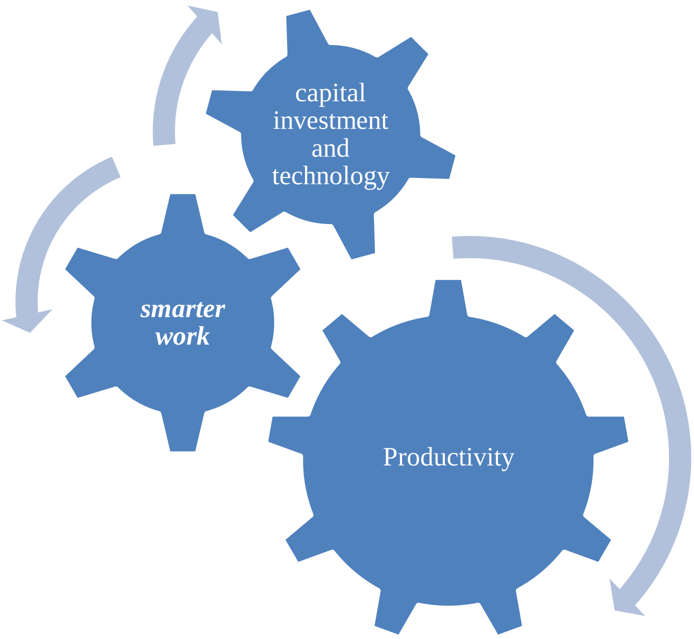


Figure 1 Smarter work as essential link of productivity growth

In order to find the answer of the ''How to work smarter?'' question one differentiates two aspects:

- *Automatization* with the help of industrial robots, and
- *Optimization* both the quantitative and qualitative aspects of the managerial decisions by using the symbolic reasoning capabilities of the computer. One may capture and

[2] Isoc, D. (2012), *Ghid de acţiune contra plagiatului: buna-conduită, prevenire, combatere*, p. 208

use the domain experts knowledge in order to become available any place any time for the company.

According to Lieberman B.A. (2012), the **Just-in-Time supply chain** is an example of business process **driven by the rules**[3]. This statement, also, offers a confirmation of ours assumptions.

Therefore, we may state that the proposed solution in the present thesis is :

- an Intelligent System for decision making – in general, and
- a Fuzzy Expert System for control/regulate/optimise of the finished goods inventory – in particular.

Because of the fact that a decision-making Intelligent System encapsulates the business rules as first module, we must think of the rule-based systems.

The knowledge representation in the IF-THEN rules form is particular to Expert Systems/ A.I.

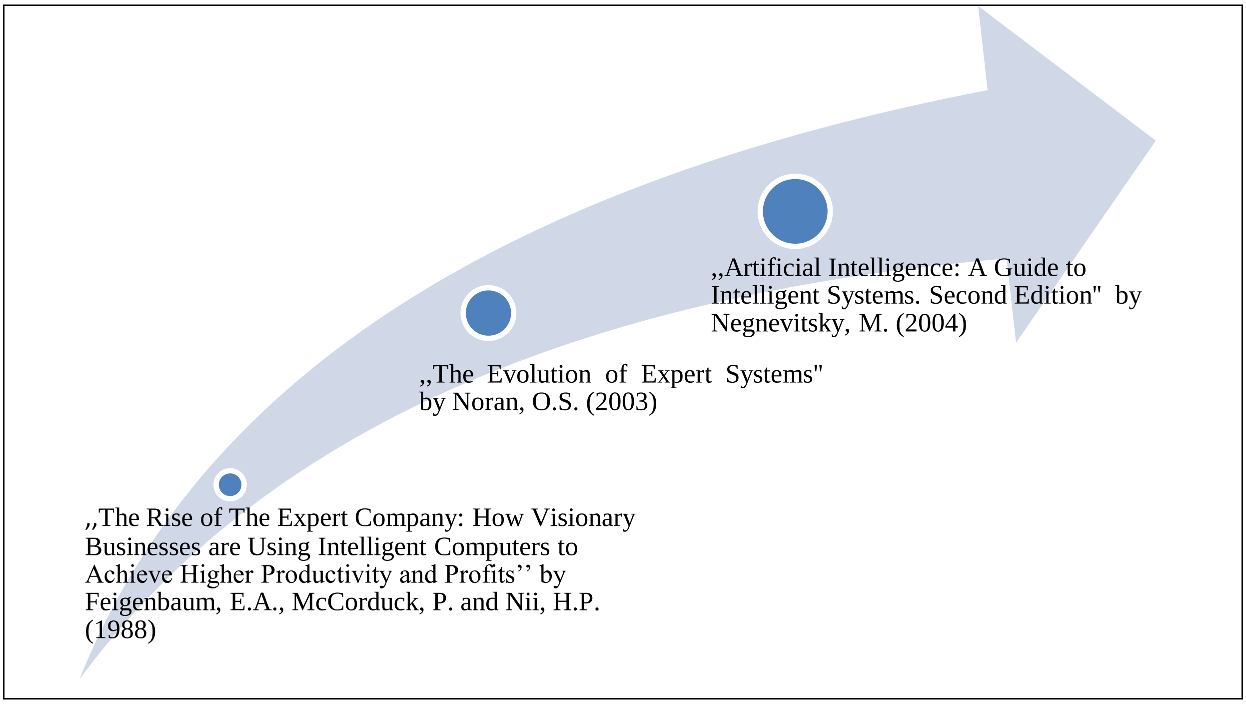


Figure 2 Main papers used to built Expert Systems' reference state

The basic two components of an ES are:

- *knowledge base, and*

[3] Lieberman, B.A. (2012), Requirements for rule engines: Capture and communication of complex business rules, IBM developerWorks®, *URL: http://www.ibm.com/developerworks/library/os-rulesengines/os-rulesengines-pdf.pdf [Accesat la data de 10 februarie 2014]*, p. 2

- *inference/ reasoning engine,* that can operates:
  a) *forward* – from conditions to conclusions,
  b*) backward* – from conclusions to conditions.

The main benefit of an ES is the company's local knowledge (i.e. the *métis*) valuation. Therefore, in this respect, an ES differs from a conventional computer program.

In the present thesis the proposed ES is a small one, so the work for its development implies months-person.

1.2 Reference state of Fuzzy Expert Systems

In order to overcome the *knowledge-bottleneck* effect, we must step into the world of hybrid Expert Systems. If we take into account the aspect of fuzzy defined problems, we may choose an Fuzzy Expert System as a solution.

Therefore: FES=ES + FUZZY LOGIC

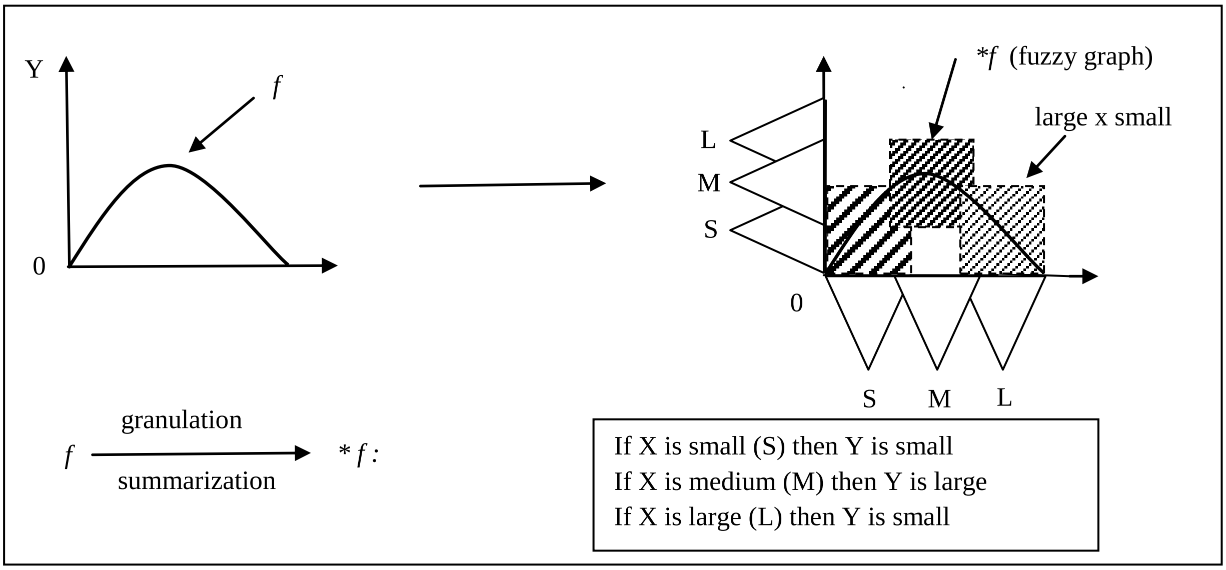


Figure 3 Granulation of a function *f*
after Zadeh, L.A. (2008), „Is there a need for fuzzy logic?", Information Sciences 178, 2008, pp. 2751-2779, p. 2756

In the case of Fuzzy Expert Systems there is the possibility to represent the knowledge base in a tabular form, which is a type of hybridization.

The linguistic variables may be modeled as triangular fuzzy numbers:

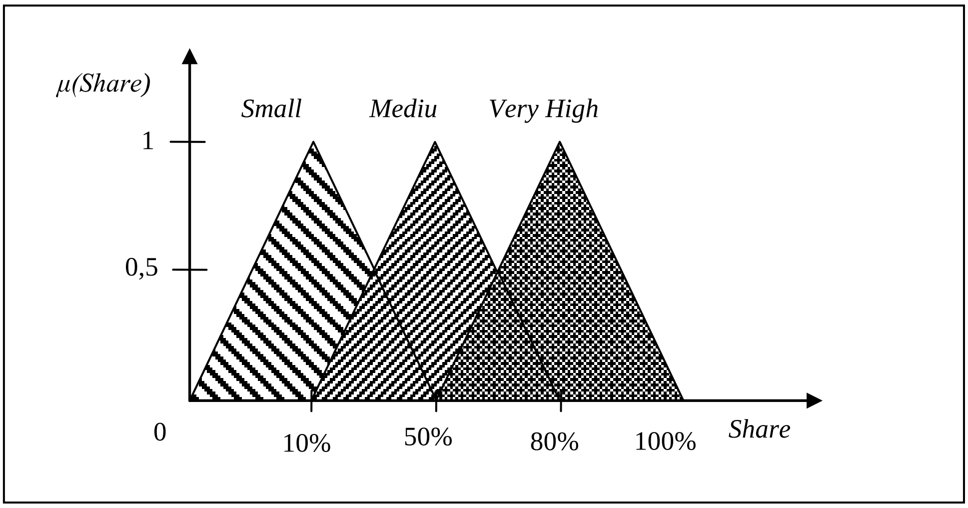


Figura 4 A fuzzy set modeling

1.3 Reference state of inventory management theory

In the 1980's, Michael Porter presented the value chain concept. Since then, the inherent processes of a supply chain were seen as a guide to support business decisions.

From 1996 the SCOR is a reference model, that offers the access to best practices and benchmarking, although ''does not provide any optimization methods''.[4]

Tabel 1 Main elements used to built the reference state of inventory management theory

Books and manuals	Canonical knowledge used in the present thesis
Bălan, C. (2006), *Logistica.*	Inventory definition, stock types, analysis of stock keeping, esential decisions in inventory control
Jacobs, F.R. and Chase, R. (2013), *Inventory Management, Chapter 11* from *Operations and Supply Chain Management: The Core, Third ed.*	Inventory management/control models
Chitale, A.K. and Gupta, R.C. (2011), *Materials Management: Text and Cases. Second Edition*.	Formulas: • stock rotation rate • acceptable stock rotation rate
Jensen P.A. & Bard J.F. (2003), *Operations Research Models and Methods (Website).*	Equations: • excess and shortage, in the case of uniform/rectangular demand distribution, and • expected profit, according to the probabilistic single period inventory model

[4] Sürie, C. and Wagner, M. (2008), „*Supply chain analysis'', p. 41*

PART II: Research methodology (design)

2.1 Research hypotheses

- *If the performance of an human expert may be captured into the rules form of knowledge then choosing an Expert System for decision-making, from the Intelligent Systems range, is advisable.*

- *If the reality aspects are described by the expert using his regular language (not the formal/mathematical language) then fuzzy logic (not boolean logic) is suited.*

- *If the control is the specific task of inventory management (inventory regulation) then choosing a Fuzzy Expert System is advisable (because of the numeric processing capability that complements the symbolic reasoning of a classical ES).*

- *If the Fuzzy Expert System model is built on a probabilistic single period inventory model basis, then using the dynamic prices strategy is possible.*

2.2 Research objectives

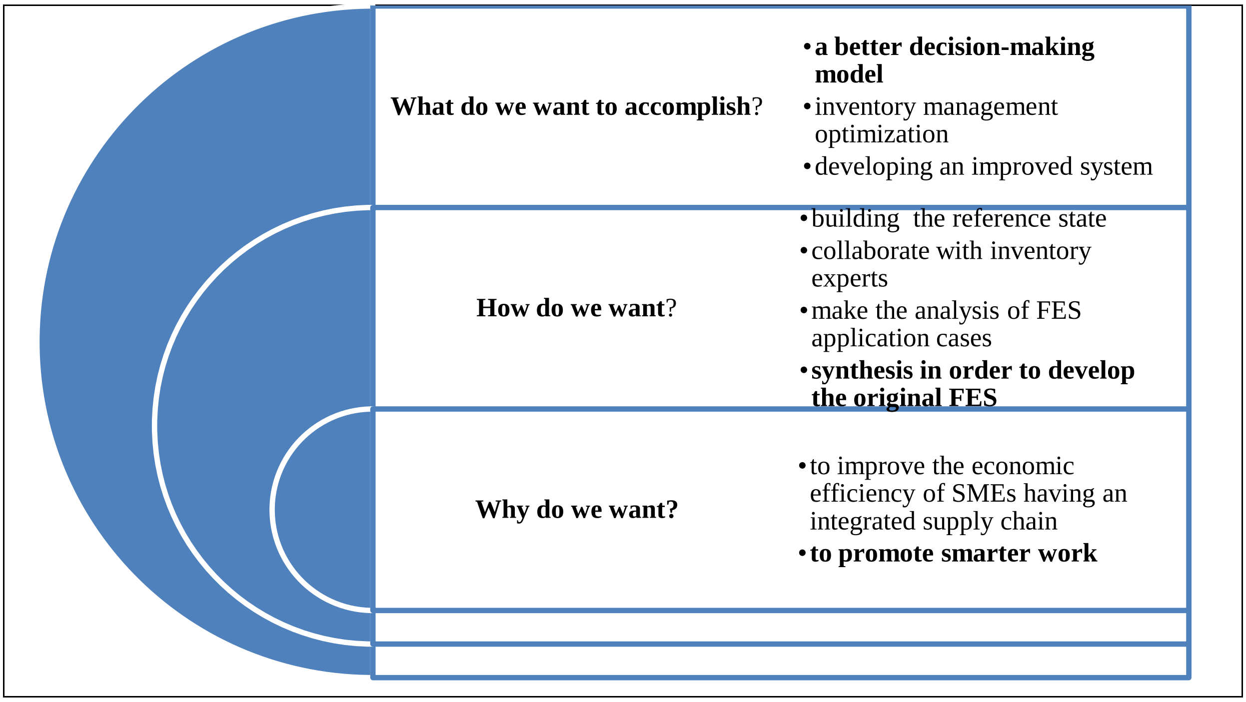


Figura 5 Obiectivele propuse în prezenta teză

2.3 Used methods

2.3.1 Specialized literature study (investigation) (the State-of-the-Art)

Having the four developed research hypotheses as guide, we have investigated the specialized literature in order to clarify and accomplish the objectives proposed.

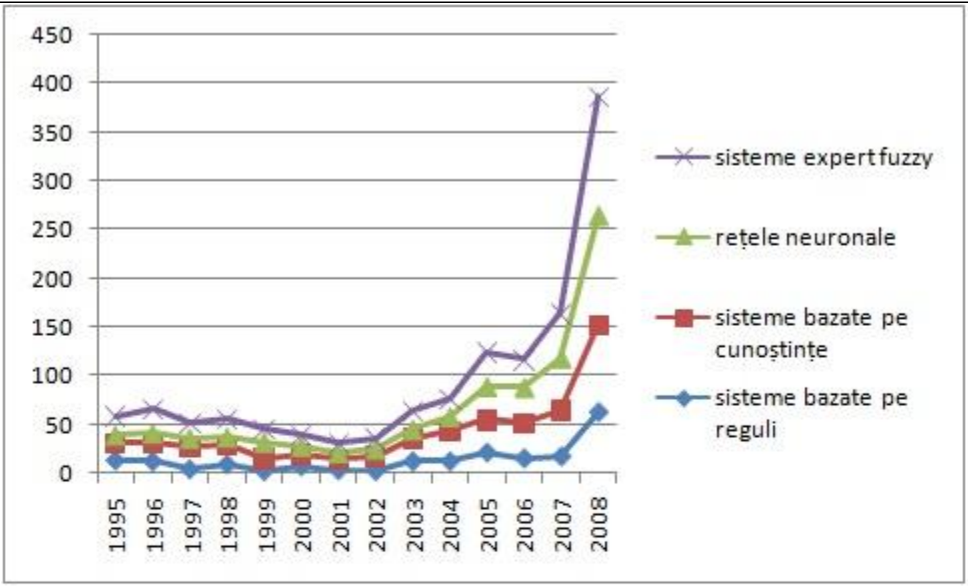


Figure 6 Hybrid Expert Systems' trends, extract from
Shiau, W.L. (2011), ,, A profile of information systems research published in expert systems with applications from 1995 to 2008'', Expert Systems with Applications 38 (2011), p. 4002

2.3.2 Compared analysis of Fuzzy Expert Systems' application cases in inventory management

Guiffrida, A.L. (2009), *Fuzzy Inventory Models*

- surveys 83 fuzzy inventory models, grouped into 7 categories
- analyses the fuzzy logic application in inventory management models' creation

Ziukov, S. (2015), ,, A Literature Review on Models of Inventory Management Under Uncertainty''

- surveys 30 papers
- classifies the fuzzy inventory models into 4 groups, after 7 criterias: dimension, period, number of stocking points, the nature of product, demand and replenishment process, deficits and penalties
- analyses the fuzzy models' characteristics

Stoia, C.L. (2014), ,,An Analysis Regarding the Possibility of Using Fuzzy Logic in Inventory management''

- surveys a few recent fuzzy models having as inputs the fuzzy defined level both of demand and the availability of supply
- provides a brief guide to develop a fuzzy control system with the help of available tools, and
- proposes a simple model with 2 IN/2 OUT and 6 rules

Figure 7 The synthesis of contributions used in FES application cases' analysis

2.3.3 Synthesis of application cases in order to design an improved system

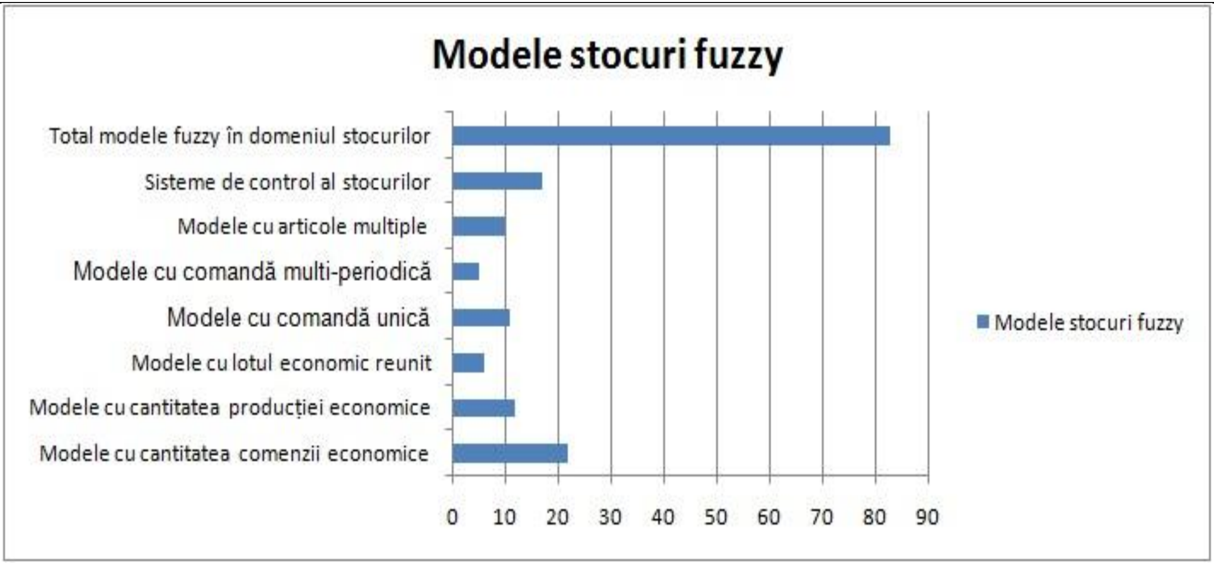


Figure 8 Inventory fuzzy models, own synthesis
after Guiffrida, A.L. (2009), ,,Fuzzy Inventory Models'', în: Jaber, M.Y. (ed.), Inventory Management: Non-Classical Views [Chapter 8], CRC Press, FL, Boca Raton, 2010, pp. 173-190, URL: http://www.researchgate.net/publication/259751254_Fuzzy_Inventory_Models [Accesat la data de 11 octombrie 2015], pp. 182-192

See, also, relevant information in the paper of Stoia, C.L. and Achim, I.M. (2015): *''A Synthesis Regarding the Application of Expert Systems in Inventory management.''*[5] .

[5] Stoia, C.L. and Achim, I.M. (2015), ,,A Synthesis Regarding the Application of Expert Systems in Inventory management'', *2015 IEEE International Conference on Industrial Technology (ICIT), 17-19 March 2015, Seville, pp. 2382 – 2387*, DOI: 10.1109/ICIT.2015.7125449, IEEE

2.5 Developing of the original inventory control (regulate) system

2.5.1 Theoretical (conceptual) proposed model

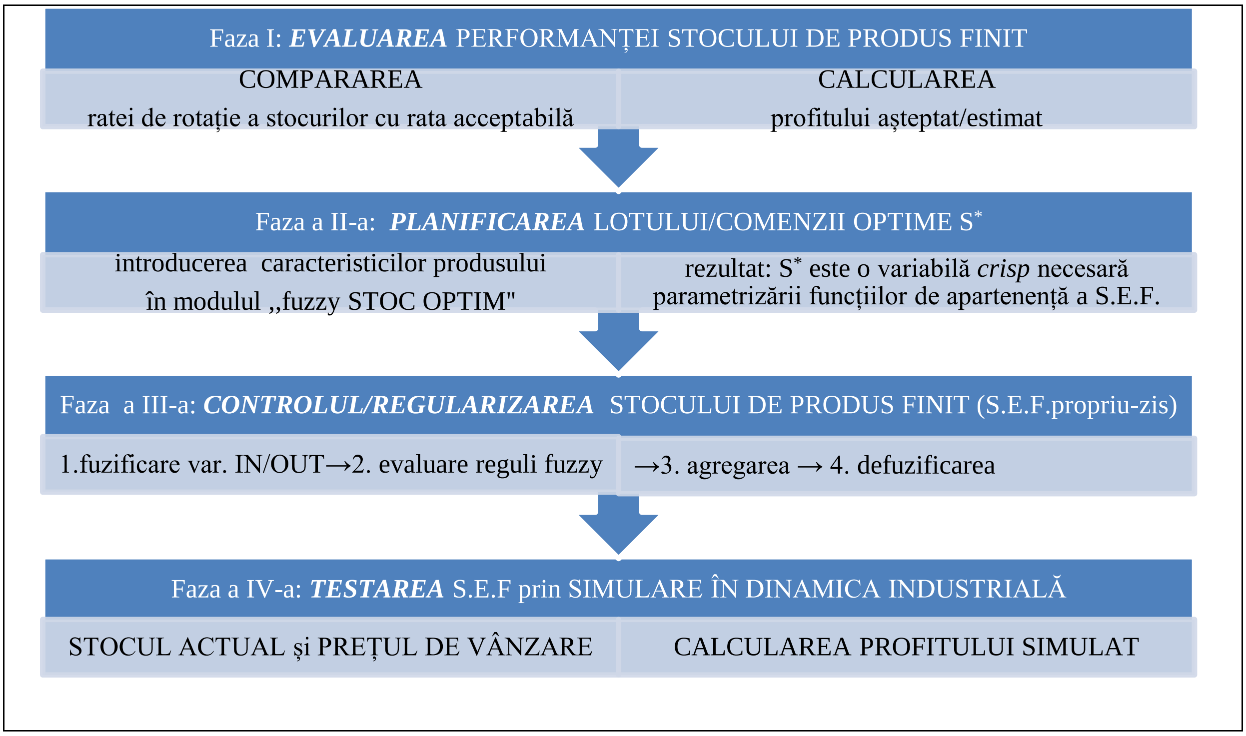


Figure 9 Conceptual scheme of the proposed model

2.5.2 Fuzzylite 3.1 software modeling of system in fuzzy control approach

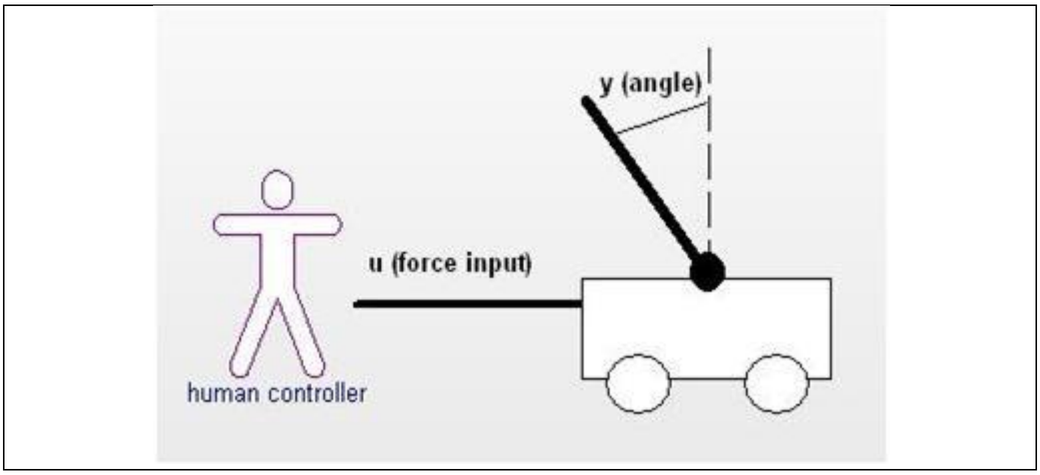


Figura 10 Stabilizarea unui pendul așezat invers

Table 2 The analogy's presentation of the proposed FES idea

Fuzzy control system's variables	The inverted pendulum model after Passino şi Yurkovich (1997)	Inventory control model THE ANALOGY
Input: e (t)	The angle error, between vertical and pendulum position	The error between forecasted demand and real demand
Input: $\frac{d}{dt}e(t)$	The change in (angle) error rate, with respect to time	UNDEVELOPED
Input: $\int e(t)dt$	UNDEVELOPED	The error between forecasted production quantity (DESIRED INVENTORY) and actual sales
Output: u(t)	Applied force	Sale price manipulation

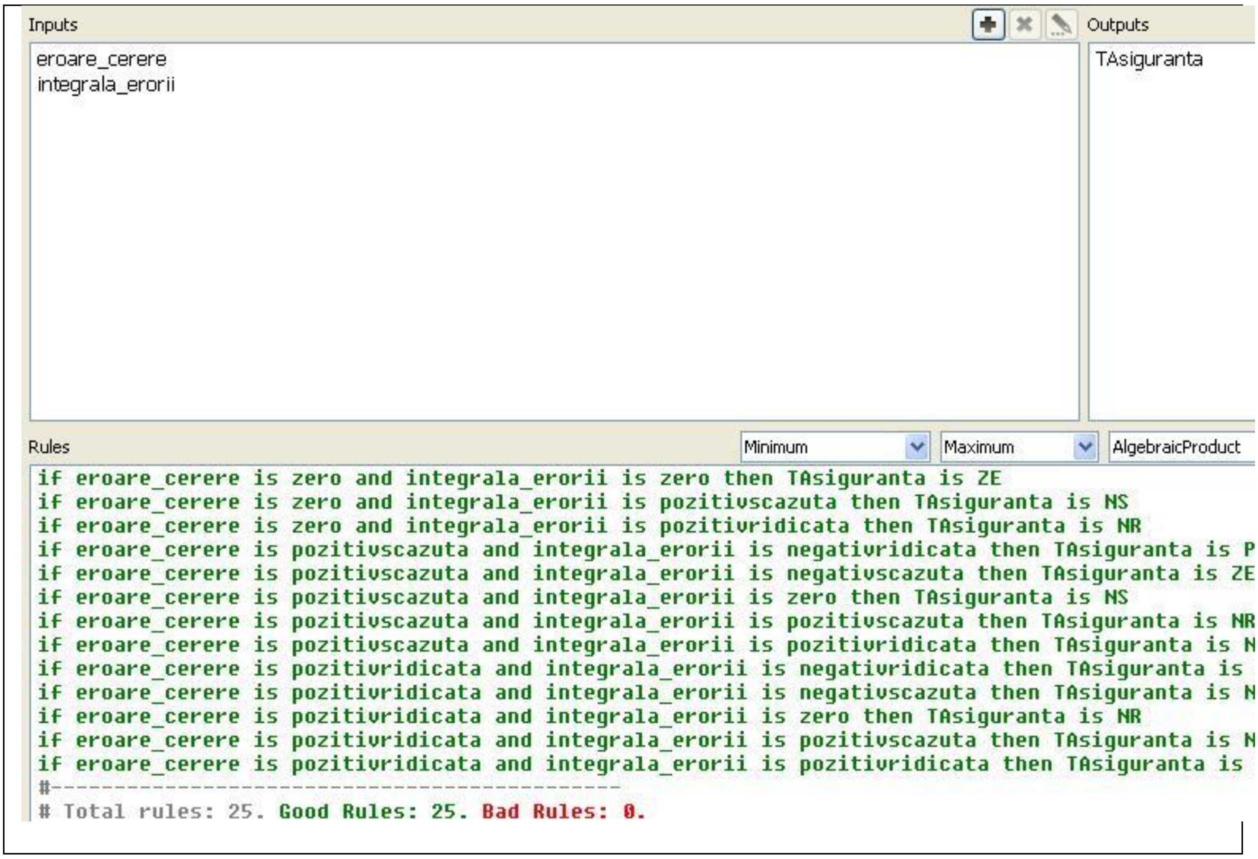


Figure 11 The processed rules in FuzzyLite 3.1

Table 3 FES inputs in the system-language of FuzzyLite 3.1:

FUZZIFY eroare_cerere RANGE := (-100.000 .. 100.000); TERM negativridicata := Ramp (-25.000, -100.000); TERM negativscazuta := Triangle (-50.000, -25.000, 0.000); TERM zero := Triangle (-10.000, 0.000, 10.000); TERM pozitivscazuta := Triangle (0.000, 25.000, 50.000); TERM pozitivridicata := Ramp (25.000, 100.000); END_FUZZIFY	FUZZIFY integrala_erorii RANGE := (-200.000 .. 200.000); TERM negativridicata := Ramp (-50.000, -200.000); TERM negativscazuta := Triangle (-100.000, -50.000, 0.000); TERM zero := Triangle (-20.000, 0.000, 20.000); TERM pozitivscazuta := Triangle (0.000, 50.000, 100.000); TERM pozitivridicata := Ramp (50.000, 200.000); END_FUZZIFY

Table 4 FES output in the system-language of FuzzyLite 3.1:

DEFUZZIFY TAsiguranta RANGE := (-15.000 .. 15.000); TERM NR := Ramp (-8.000, -15.000); TERM NS := Triangle (-12.000, -8.000, 0.000); TERM ZE := Triangle (-4.000, 0.000, 4.000); TERM PS := Triangle (0.000, 8.000, 12.000); TERM PR := Ramp (8.000, 15.000);	FUNCTION_BLOCK VAR_INPUT eroare_cerere: REAL; integrala_erorii: REAL; END_VAR VAR_OUTPUT TAsiguranta: REAL; END_VAR

Table 5 Aggregation and defuzzify phases:

RULEBLOCK AND : MIN; OR : MAX; ACT : PROD;	METHOD : COG; ACCU : ASUM; DEFAULT := -inf; END_DEFUZZIFY

While the defuzzify phase is accomplished with the *Center of Gravity* method, the aggregation is done with the help of *Algebraic Sum* operator.

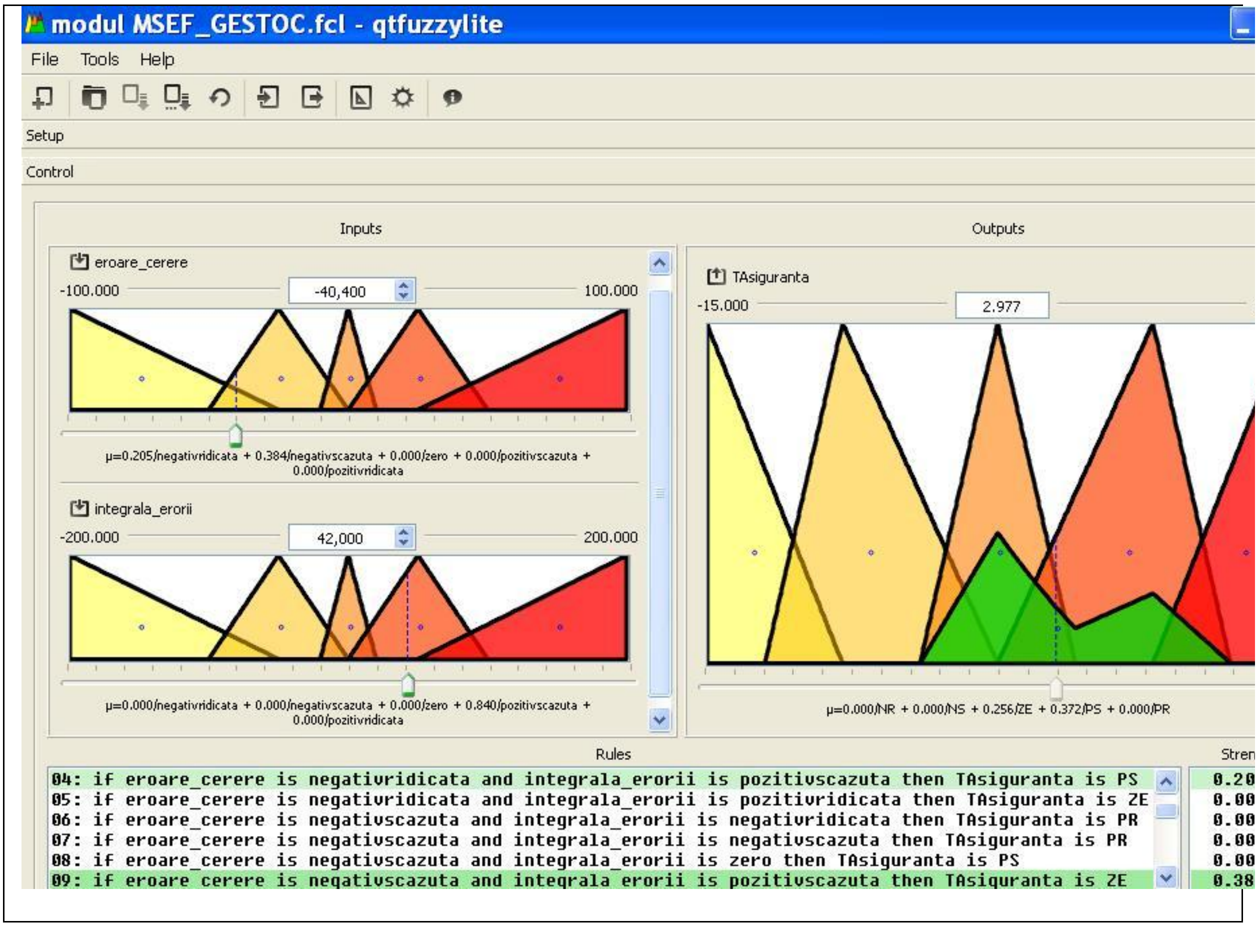


Figure 12 FES control phase

2.5.3 System Dynamics simulation with PowerSim 2.51 software

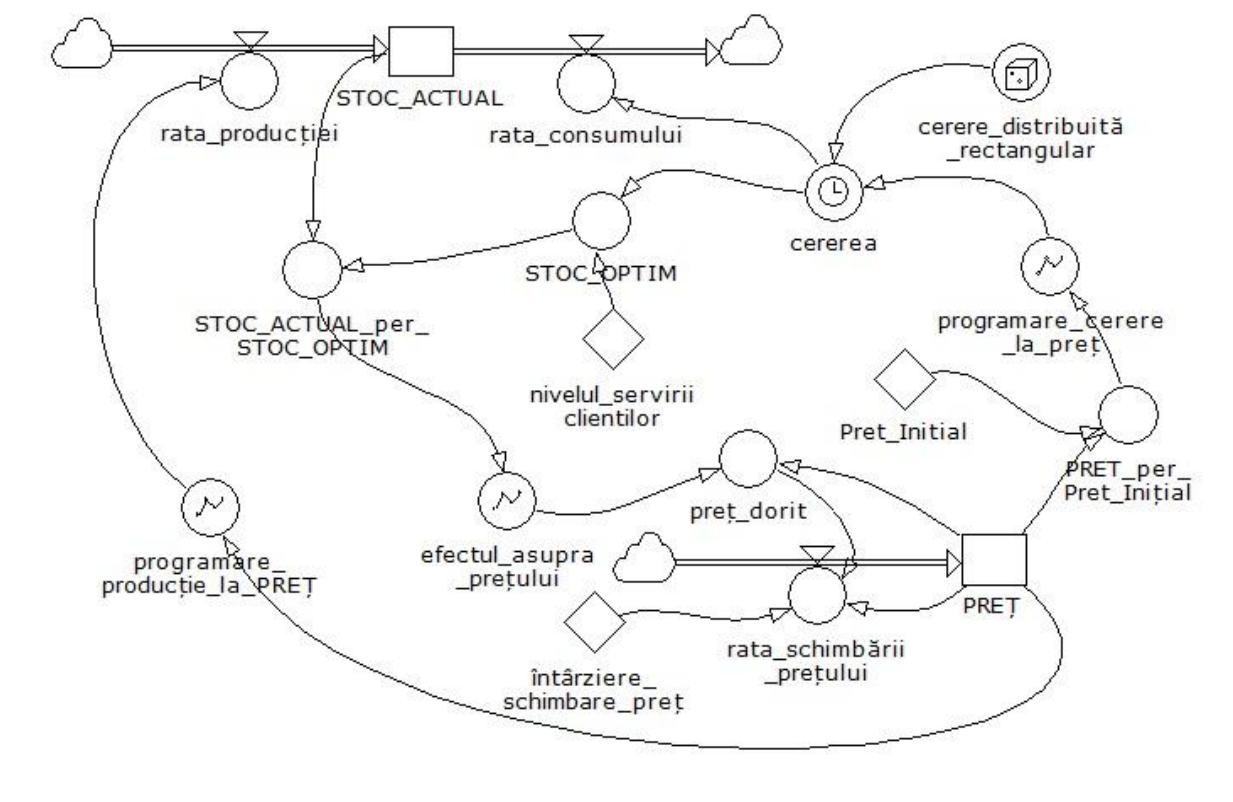


Figure 13 The adapted simulation model with PowerSim 2.51 software

The above System Dynamics model was inspired by:

- Demand and supply dynamic model[6] developed in STELLA by Whelan, J. & Msefer, K. (1996), and
- The model[7] proposed by Guided Study Program in System Dynamics (1999)

Own adaptation consists in:

- *Production_price_schedule* variable was model with he help of a graph function in order to provide an economic basis of *sale price variation* used as inventory regulation instrument (Fuzzy system output or manipulated variable);
- OPTIMUM_INVENTORY variable was modeled as the product between *demand* and *customer service level* (98%);

[6] Whelan, J. & Msefer, K. (1996), „*Economic Supply & Demand*'', D-4388, M.I.T., URL: http://ocw.mit.edu/courses/sloan-school-of-management/15-988-system-dynamics-self-study-fall-1998-spring-1999/readings/economics.pdf [Accesat la data de 6 octombrie 2014], p. 20

[7] Guided Study Program in System Dynamics (1999), D-5012-1, M.I.T, URL: http://ocw.mit.edu/courses/sloan-school-of-management/15-988-system-dynamics-self-study-fall-1998-spring-1999/assignments/soln28.pdf [Accesat la data de 2 septembrie 2015], p. 4

- *Normal_demand* variable from the initial model[8] being a constant, I have replaced it with the *RANDOM()* function in order to model a uniform/rectangular demand distribution with a minimum limit of 10 kg per day and a maximum limit of 40 kg/day.
- I have developed the model with the help of PowerSim 2.51 tool; the inspired models being developed with the help of STELLA, respectively VENSIM tools.
- I have replaced the data according to the Fuzzy system needs.

[8] Ibidem, p. 4

PART III Model testing of S.C. Transeuro's case studies

3.1 Presentation of Transeuro company

Transeuro company from Ighiu, Alba county, is on the bakery market since 1991, respectively on the meat preparations (products) market since 2002.

The company has an integrated supply chain that makes the difference on the county market, where it competes the national level companies such is Elit Cugir.

3.2 Transeuro's inventory policy analysis

The products policy in the company has the following characteristics:

- There are one hundred meat preparations that are sold using both its distribution network and the twelve presentation-stores. The share sale by the latter is ≈ 32% of the production of meat preparations.
- Qualitative analysis of of finished goods inventory control, in terms of FSN classification:
    - The first 10 types of meat preparations have a monthly turnover of over 1000 kg, so falls into the category F;
    - The last 20 varieties sold are under 100kg amounts per month, so they are the type N;
    - S category of products includes the other 70 varieties between 100 kg and 1000 kg per month.

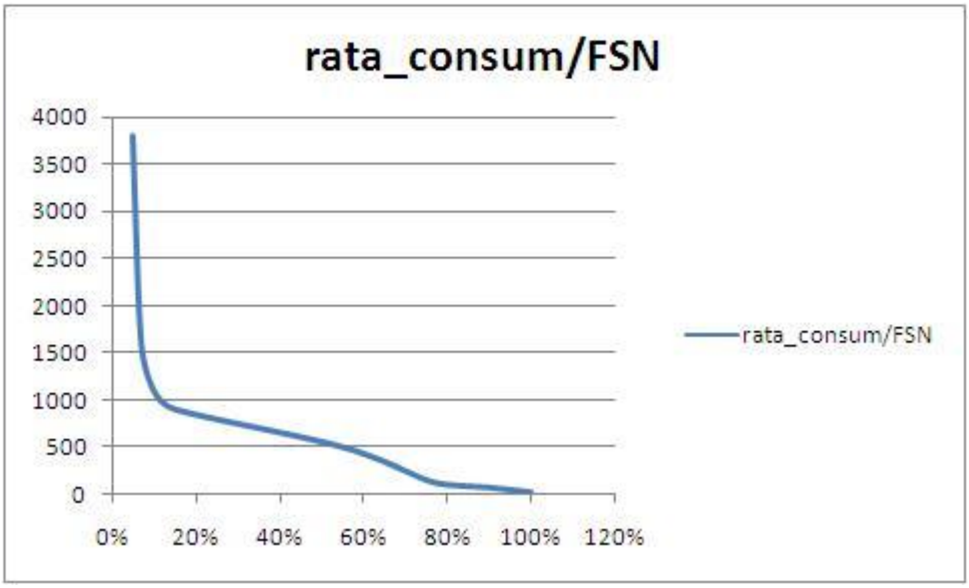


Figure 14 FSN classification of Transeuro products

On the horizontal axis is the percentage of the total of 100 varieties, and vertically - monthly amount produced, with values between 20 kg and 3800 kg**.**

3.3 Human expert's reasoning description

At Transeuro company, the integrated value chain management policy, limited to the twelve presentation-stores, follows the model below.

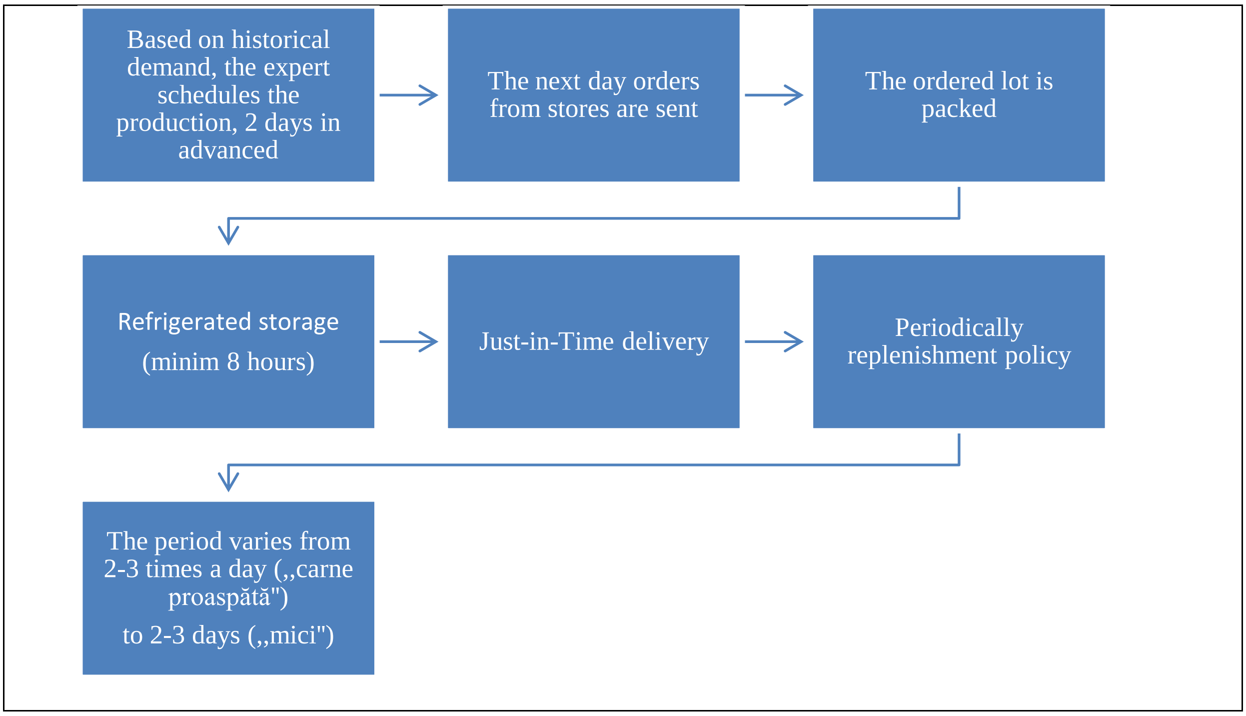


Figure 15 The simplified reasoning model of the Transeuro value chain management

The next step is the design of control. Initially, the consumption rate must be measured. To assess the rate of consumption we can use as a model FSN classification algorithm described in Stoia & Achim (2015).[9]

The meat preparations with a high consumption rate (F type) used to test the model being similar to the ones of A-type (in Pareto classification), we treated them from JIT perspective, in the same manner as the Transeuro experts in inventory management did.

The Transeuro inventory policy is close to the JIT approach, having an empirical basis. It is, also, very effective due to existing expertise within the company.

We managed a scientific Just-in-Time approach by designing the Fuzzy Expert System to integrate this expertise.

[9] Parekh et al. (2008) ***apud*** Stoia, C.L. and Achim, I.M. (2015), „A Synthesis Regarding the Application of Expert Systems in Inventory management'', *2015 IEEE International Conference on Industrial Technology (ICIT), 17-19 March 2015, Seville, pp. 2382 – 2387*, DOI: 10.1109/ICIT.2015.7125449, *p. 2384*

3.4 Case study of ''virşli maţ de oaie'' product

3.4.1 Evaluation of ''virşli maţ de oaie'' product

Comparing the two turnovers rates note that there is a significant difference of 24% between the current stock turnover of ≈9 and the optimal (acceptable turnover rate) of ≈12. This gap of 24% in the turnover of stocks reflects the economic efficiency of the company's cash flow (cash flow), i.e. how fast are returning the investments (the company is paid).

The fuzzy module calculates optimal stock S^* after a formula derived from Eq. 3.10:

$$S^*=[(cerere\_max - cerere\_min)*(PV + CP - CPR)]/(PV + CP - CS) + \text{cerere\_min}$$

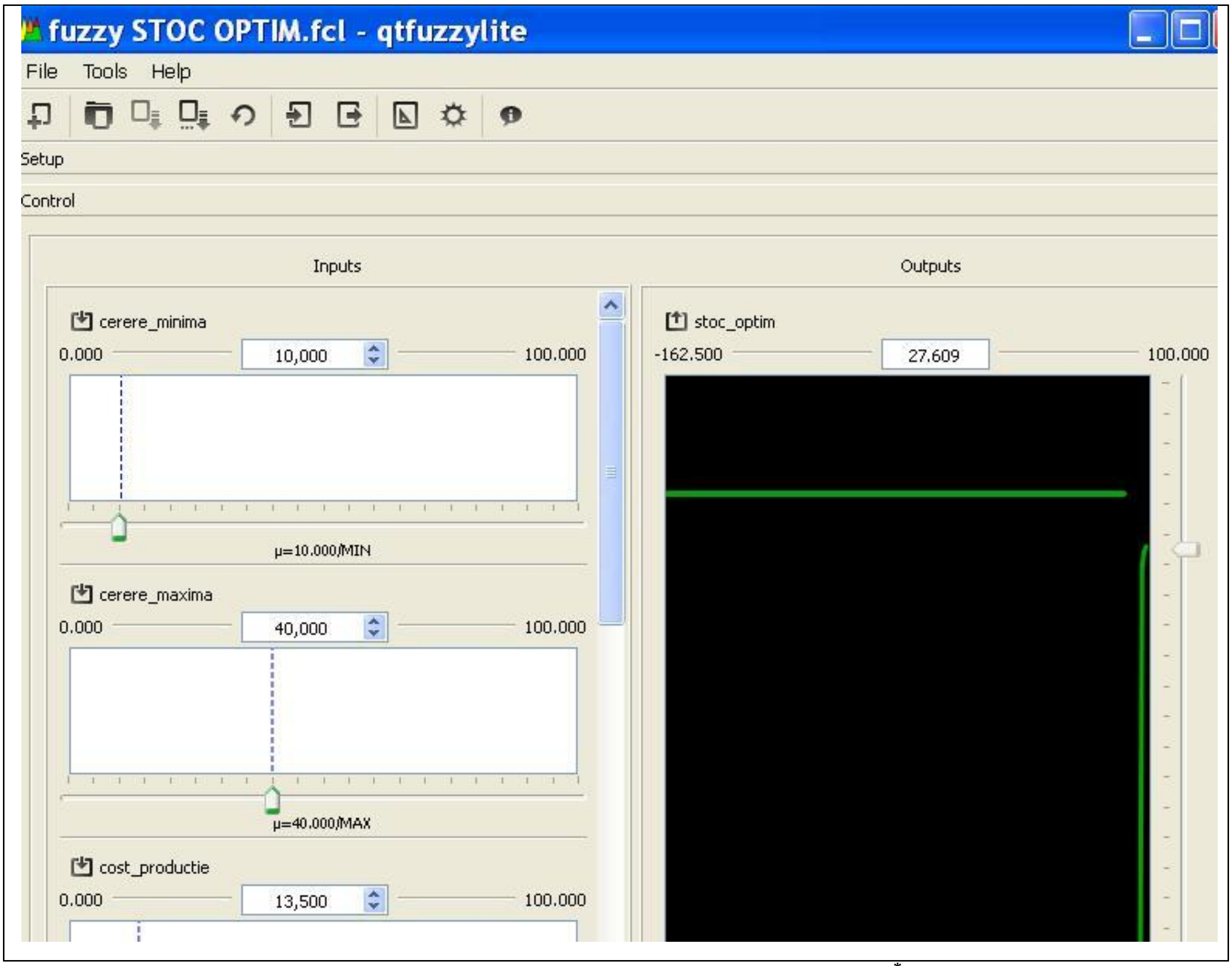


Figure 16 Optimum inventory level for „virşli'' product, S^* is 28 kg

3.4.2 Fuzzy System implementation for „virşli maţ de oaie'' inventory regulation

The first step is determining benchmarks for both inputs and outputs fuzzy system. The thresholds required for the *error* membership functions are:

- $\frac{1}{8}S^*$=3,5 kg;
- $\frac{1}{4}S^*$=7 kg;
- $\frac{3}{8}S^*$=10,5 kg;
- $\frac{1}{2}S^*$=14 kg.

The thresholds required for the *integral of error* membership functions are:

- $\frac{1}{4}S^*$=7 kg;
- $\frac{1}{2}S^*$=14 kg;
- $\frac{3}{4}S^*$=21 kg;
- S^*=28kg.

The thresholds required for the *sale price variation* membership functions (FES output):

- $\frac{PV}{10}$ =2lei;
- $\frac{2PV}{10}$ =4lei;
- $\frac{3PV}{10}$ =6lei;
- $\frac{4PV}{10}$ =8lei.

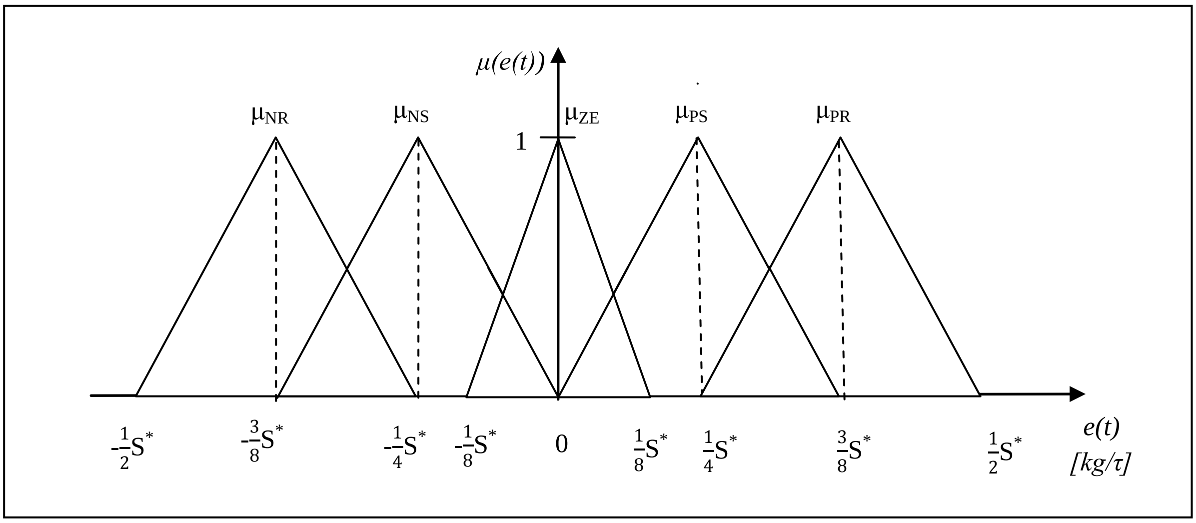


Figure 17 Demand *error* membership functions for„virşli maţ de oaie'' product on τ period

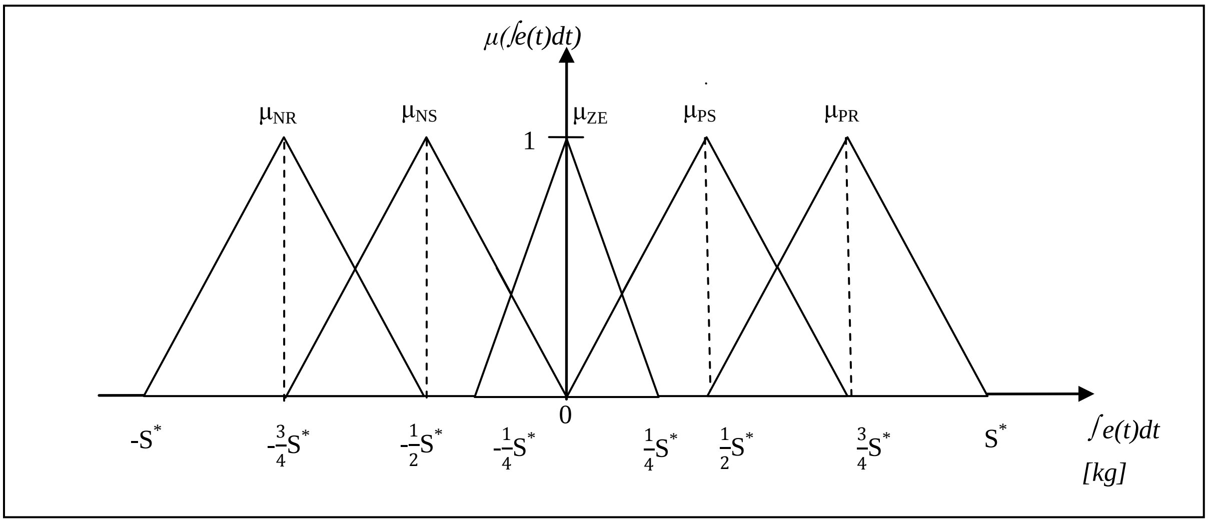


Figure 18 *Integral of error* membership functions for „virşli maţ de oaie''

The second step is to establish rules for implementing FES for inventory management. This phase is shown in the table below.

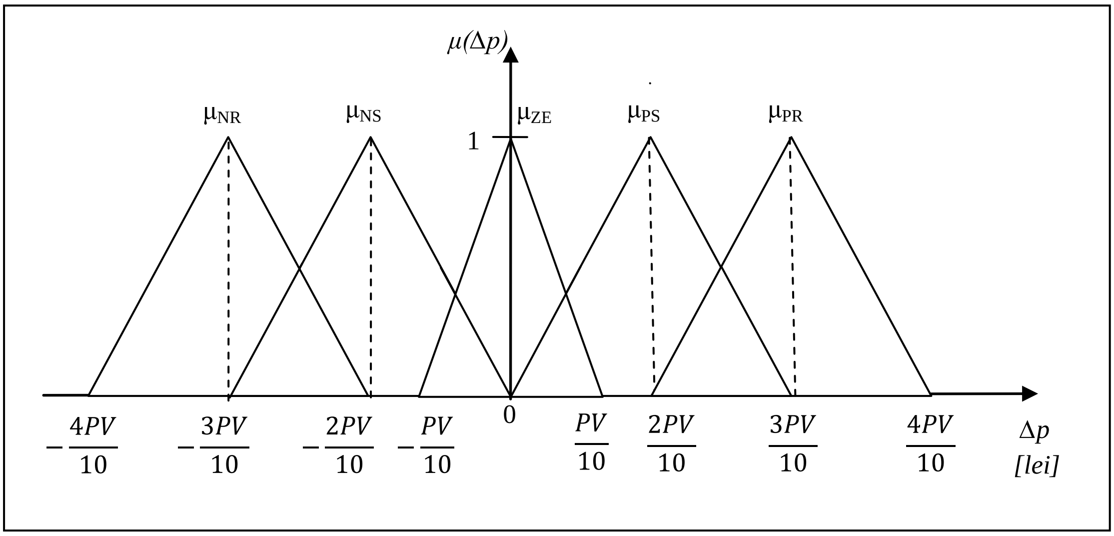


Figure 19 FES output membership functions Funcţiile for „virşli maţ de oaie'' product

To build the FES model I used Fuzzy Lite 3.1 software developed by Juan Rada-Vilela[10].

Table 6 FES outputs fuzzification stage for „virşli maţ de oaie''

FUZZIFY eroare_cerere RANGE := (-14.000 .. 14.000); TERM negativridicata := Triangle (-14.000, -10.500, -7.000); TERM negativscazuta := Triangle (-10.500, -7.000, 0.000); TERM zero := Triangle (-3.500, 0.000, 3.500); TERM pozitivscazuta := Triangle (0.000, 7.000, 10.500); TERM pozitivridicata := Triangle (7.000, 10.500, 14.000); END_FUZZIFY	FUZZIFY integrala_erorii RANGE := (-28.000 .. 28.000); TERM negativridicata := Triangle (-28.000, -21.000, -14.000); TERM negativscazuta := Triangle (-21.000, -14.000, 0.000); TERM zero := Triangle (-7.000, 0.000, 7.000); TERM pozitivscazuta := Triangle (0.000, 14.000, 21.000); TERM pozitivridicata := Triangle (14.000, 21.000, 28.000); END_FUZZIFY

Table 7 The twenty-five rules processing phase

RULE 1 : if eroare_cerere is negativridicata and integrala_erorii is negativridicata then variatia_pretului is PR RULE 2 : if eroare_cerere is negativridicata and integrala_erorii is negativscazuta then variatia_pretului is PR RULE 3 : if eroare_cerere is negativridicata and integrala_erorii is zero then variatia_pretului is PR RULE 4 : if eroare_cerere is negativridicata and integrala_erorii is pozitivscazuta then variatia_pretului is PS RULE 5 : if eroare_cerere is negativridicata and integrala_erorii is pozitivridicata then variatia_pretului is ZE RULE 6 : if eroare_cerere is negativscazuta and integrala_erorii is negativridicata then variatia_pretului is PR RULE 7 : if eroare_cerere is negativscazuta and integrala_erorii is negativscazuta then variatia_pretului is PR RULE 8 : if eroare_cerere is negativscazuta and integrala_erorii is zero then variatia_pretului is PS RULE 9 : if eroare_cerere is negativscazuta and integrala_erorii is pozitivscazuta then variatia_pretului

[10] Juan Rada-Vilela (2014), Fuzzylite: a fuzzy logic control library, *URL: http://www.fuzzylite.com [Accesat la data de 7 ianuarie 2014]*

```
is ZE
RULE 10 : if eroare_cerere is negativscazuta and integrala_erorii is pozitivridicata then
variatia_pretului is NS
RULE 11 : if eroare_cerere is zero and integrala_erorii is negativridicata then variatia_pretului is PR
RULE 12 : if eroare_cerere is zero and integrala_erorii is negativscazuta then variatia_pretului is PS
RULE 13 : if eroare_cerere is zero and integrala_erorii is zero then variatia_pretului is ZE
RULE 14 : if eroare_cerere is zero and integrala_erorii is pozitivscazuta then variatia_pretului is NS
RULE 15 : if eroare_cerere is zero and integrala_erorii is pozitivridicata then variatia_pretului is NR
RULE 16 : if eroare_cerere is pozitivscazuta and integrala_erorii is negativridicata then
variatia_pretului is PS
RULE 17 : if eroare_cerere is pozitivscazuta and integrala_erorii is negativscazuta then
variatia_pretului is ZE
RULE 18 : if eroare_cerere is pozitivscazuta and integrala_erorii is zero then variatia_pretului is NS
RULE 19 : if eroare_cerere is pozitivscazuta and integrala_erorii is pozitivscazuta then
variatia_pretului is NR
RULE 20 : if eroare_cerere is pozitivscazuta and integrala_erorii is pozitivridicata then variatia_pretului
is NR
RULE 21 : if eroare_cerere is pozitivridicata and integrala_erorii is negativridicata then
variatia_pretului is ZE
RULE 22 : if eroare_cerere is pozitivridicata and integrala_erorii is negativscazuta then
variatia_pretului is NS
RULE 23 : if eroare_cerere is pozitivridicata and integrala_erorii is zero then variatia_pretului is NR
RULE 24 : if eroare_cerere is pozitivridicata and integrala_erorii is pozitivscazuta then variatia_pretului
is NR
RULE 25 : if eroare_cerere is pozitivridicata and integrala_erorii is pozitivridicata then variatia_pretului
is NR
```

The rules evaluation is the second phase of the FES.

Table 8 Fuzzy operators

```
RULEBLOCK
AND : MIN;
OR : MAX;
ACT : PROD;
```

Aggregation stage (III) is realised with the help of *ASUM* (Algebraic Sum) method, and the defuzzification process (IV) is accomplish with the Center of Gravity method:

Table 9 FES output defuzzification for „virşli maţ de oaie'' product

DEFUZZIFY variatia_pretului	METHOD : COG;
RANGE := (-8.000 .. 8.000);	ACCU : ASUM;
TERM NR := Triangle (-8.000, -6.700, -4.000);	DEFAULT := -inf;
TERM NS := Triangle (-6.700, -4.000, 0.000);	END_DEFUZZIFY
TERM ZE := Triangle (-2.000, 0.000, 2.000);	
TERM PS := Triangle (0.000, 4.000, 6.700);	
TERM PR := Triangle (4.000, 6.700, 8.000);	

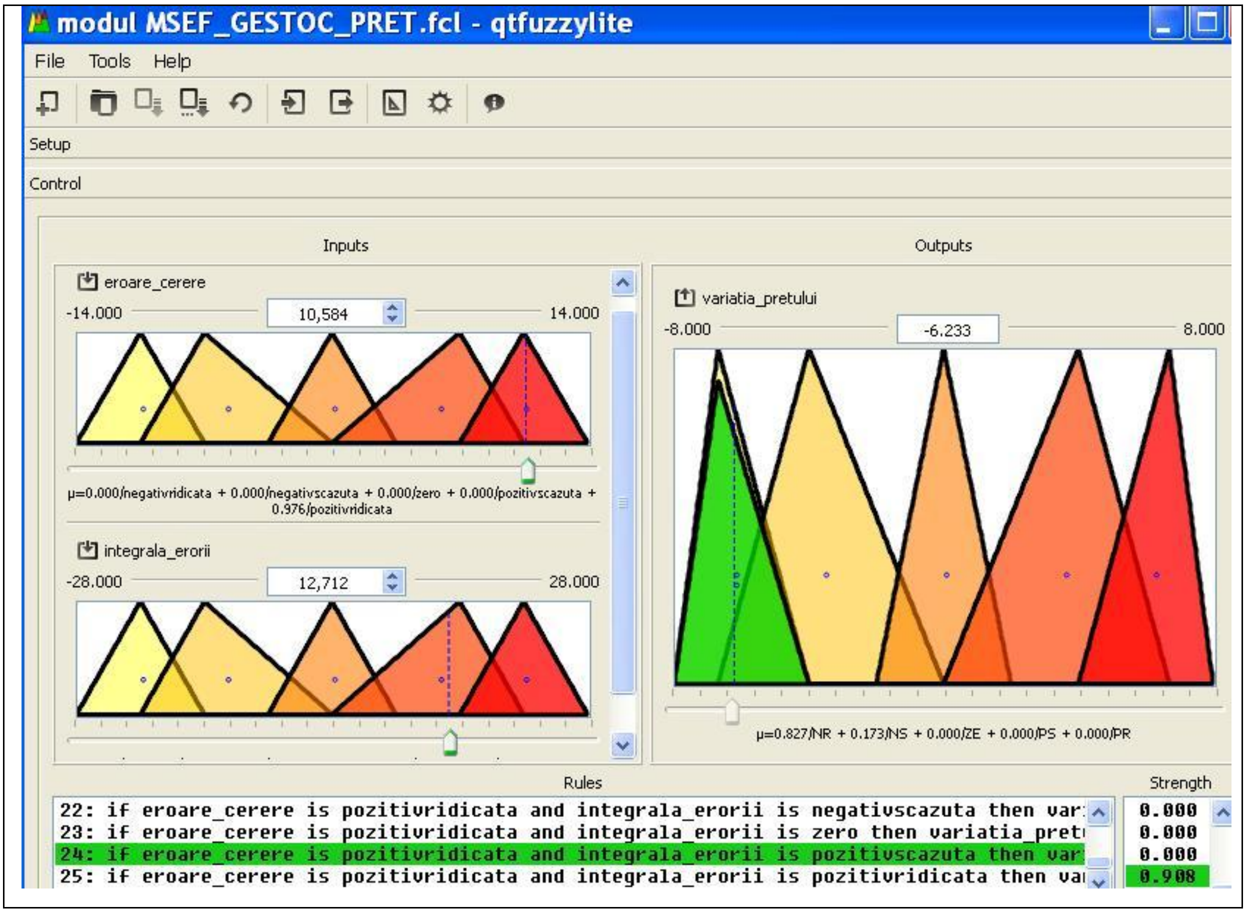


Figure 20 FES control phase for „virşli maţ de oaie''

In the figure above we see that the two sliders positions evoke the following situation:

- After a τ time elapsed from the beginning of sales day (eg. after 4 hours) there is an demand error between forecasted and real, equal to 11 kg, i.e. e(t)=10,58 kg (the demands are instantaneous with uniform distribution);

- After another 4 hours, the integral of error being equal to 12,71 kg this means that the difference between optimum inventory S^* and real sales V(t) is equal to 13kg, therefore – the direction indicated by the two errors means that the optimum stock is not to be entirely sold by the end of sales day , if the demand is not stimulated by sale price manipulation.
- The system's solution is: Δp= - 6,23 lei, meaning to cut the sale price (20lei) with 30 percents for ,,virşli maţ de oaie'' product.
- One observes that rule no. 24 is activated with strenght 0,908, meaning a high trust degree.

3.4.3 Fuzzy System simulation of ''vişli maţ de oaie'' product

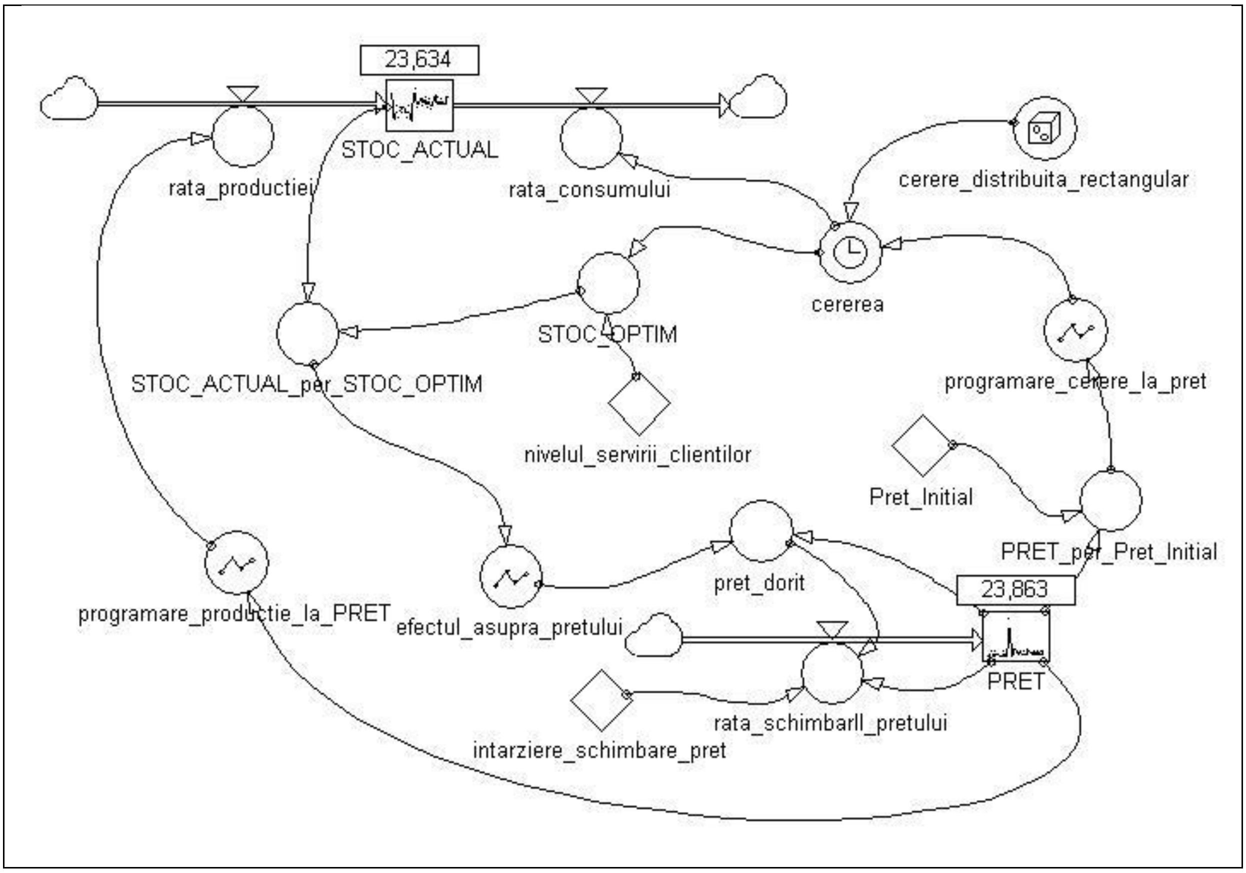


Figure 21 Simulation model for „vişli maţ de oaie'' product

The product being one with a fast-moving /high consumption of 3800 kg / month, (similar to an A-class in Pareto classification) I chosed a simulation for a period of 30 days, because this kind of products requires a firm control continuous system.

From the simulation plotted above, we see that the system stabilizes at STOC_ACTUAL: 24 kg and PRICE: 24lei. This is due, in part, to the increased demand with 10 kg each every 10 days; the random demand being modeled by a STEP (10, 10) function, commonly used for disrupting a dynamic system.

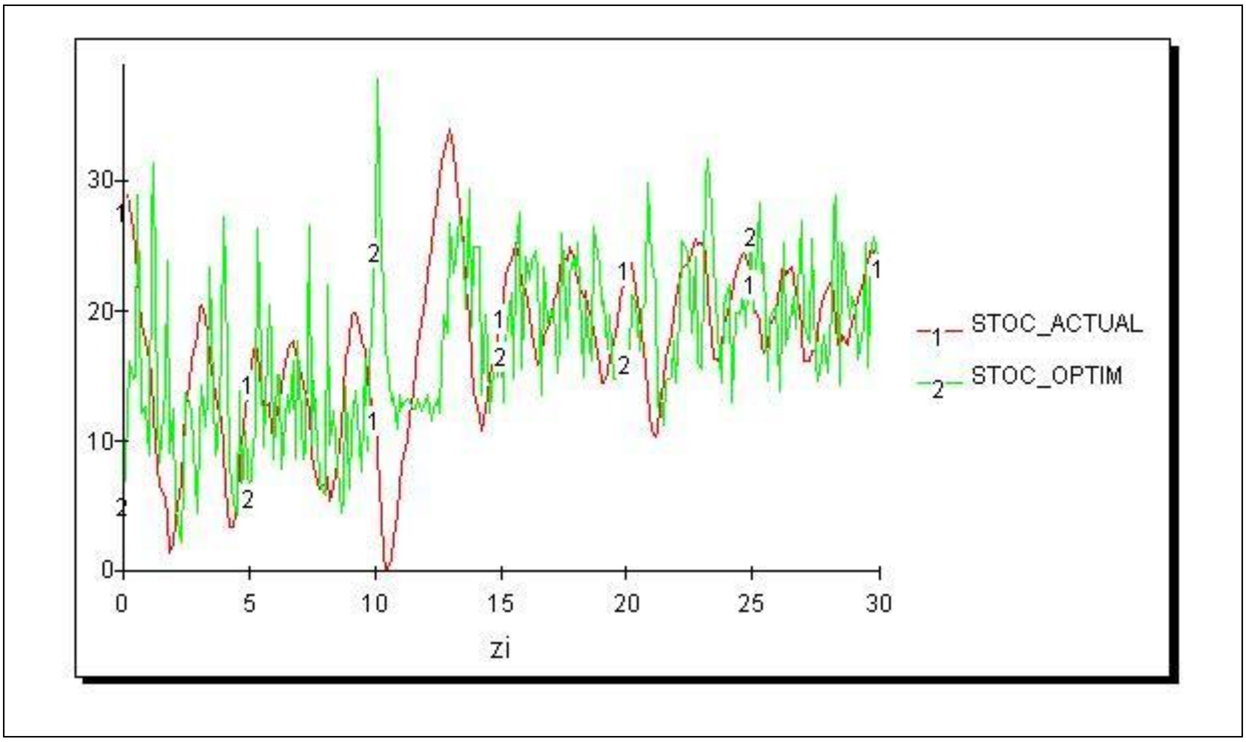


Figure 22 The inventory fluctuations graph for „virşli maţ de oaie''

The graph above illustrates a period of 30 days which STOCUL_ACTUAL oscillates larger at first, then eased to match STOCUL_OPTIM variable. This is achieved through the existence of a negative feedback loop.

La poziţia corespunzătoare zilei a 10-a observăm un vârf al STOCULUI_OPTIM, datorat modelării cererii aleatorii cu funcţia STEP(10,10), adică la fiecare 10zile creşte cererea cu 10kg.

On day 10 one observes a peak of STOC_OPTIM fluctuation, due to demand modeling with STEP (10.10) function , i.e. every 10 days the demand increases by 10 kg.

On day 20 the situation was improved and the actual stock better covers the STOC_OPTIM peak.

3.4.4 Economic efficiency proving of the Fuzzy Expert System implementation

Entering product data for „vişli maţ de oaie'' in Equation 3.9, we obtain the estimated profit if we sell the whole optimal lot:

Expected profit=20lei*25kg–13,5lei*28kg+4lei*5,4kg – (20+7lei)* 2,4kg
=500–378+21,6–64,5 ≈*79lei*.

For current stock S = 24 kg and the price PV = 24 lei / kg resulted from a periodic simulation of a month, entered in Equations 3.7 and 3.8 results the overstock and shortage estimations:

$$E_{excess}[24]=\frac{(24-10)*(24-10)}{2*(40-10)}=14^2/60=3,27kg;$$

$$E_{shortage}[24]=\frac{(40-24)*(40-24)}{2*(40-10)}=16^2/60=4,27kg;$$

Eq. 3.9 provides the *simulated profit:*

$P_{SIMULAT}$ =24lei*25kg–13,5lei*24kg+4lei*3,27kg– (24+7lei)*4,27kg
=600–324+13,08–132,37=156,71lei≈157lei

Thus, by implementing fuzzy expert control / adjustment using the stock price change, we get a relative increase of 99% (the profit doubles).

3.5 Case study of ''mici'' product in Traneuro store

3.5.1 Performance evaluation of ''mici'' product

There is a significant difference of 19% between actual turnover rate of 9.43 and the acceptable turnover rate 11.67.

This gap of 19% in turnover rate affects economic performance of the company's stock, i.e. the money invested is recovered late.

3.5.2 Fuzzy System implementation for inventory regulation of ''mici'' product

Table 10 FES first input parametrization for„mici''

Funcţia / **S^*=18kg**	μ_{NR} $(-\frac{S*}{2}, -\frac{3S*}{8}, -\frac{S*}{4})$	μ_{NS} $(-\frac{3S*}{8}, -\frac{S*}{4}, 0)$	μ_{ZE} $(-\frac{S*}{8}, 0, \frac{S*}{8})$	μ_{PS} $(0, \frac{S*}{4}, \frac{3S*}{8})$	μ_{PR} $(\frac{S*}{4}, \frac{3S*}{8}, \frac{S*}{2})$
μ(e(t))	(−9, −6,75, −4,5)	(−6,75, −4,5, 0)	(−2,25, 0, 2,25)	(0, 4,5, 6,75)	(4,5, 6,75, 9)

Tabel 11 FES second input parametrization for„mici''

Funcţia / S^*=18kg	μ_{NR} $(-S*, -\frac{3S*}{4}, -\frac{S*}{2})$	μ_{NS} $(-\frac{3S*}{4}, -\frac{S*}{2}, 0)$	μ_{ZE} $(-\frac{S*}{4}, 0, \frac{S*}{4})$	μ_{PS} $(0, \frac{S*}{2}, \frac{3S*}{4})$	μ_{PR} $(\frac{S*}{2}, \frac{3S*}{4}, S*)$
$\mu(\int e(t)dt)$	(−18, −13,5, −9)	(−13,5, −9, 0)	(−4,5, 0, 4,5)	(0, 9, 13,5)	(9, 13,5, 18)

Tabel 12 FES output parametrization for„mici''

Funcţia / P_V=15,3lei	μ_{NR} $(-\frac{4PV}{10}, -\frac{3PV}{10}, -\frac{2PV}{10})$	μ_{NS} $(-\frac{3PV}{10}, -\frac{2PV}{10}, 0)$	μ_{ZE} $(-\frac{PV}{10}, 0, \frac{PV}{10})$	μ_{PS} $(0, \frac{2PV}{10}, \frac{3PV}{10})$	μ_{PR} $(\frac{2PV}{10}, \frac{3PV}{10}, \frac{4PV}{10})$
$\mu(\Delta p(t))$	(−6, −4,5, −3)	(−4,5, −3, 0)	(−1,5, 0, 1,5)	(0, 3, 4,5)	(3, 4,5, 6)

3.5.3 System Dynamics simulation of ''mici'' product

The 3-month simulation model achieves the balance at (17kg, 17lei).

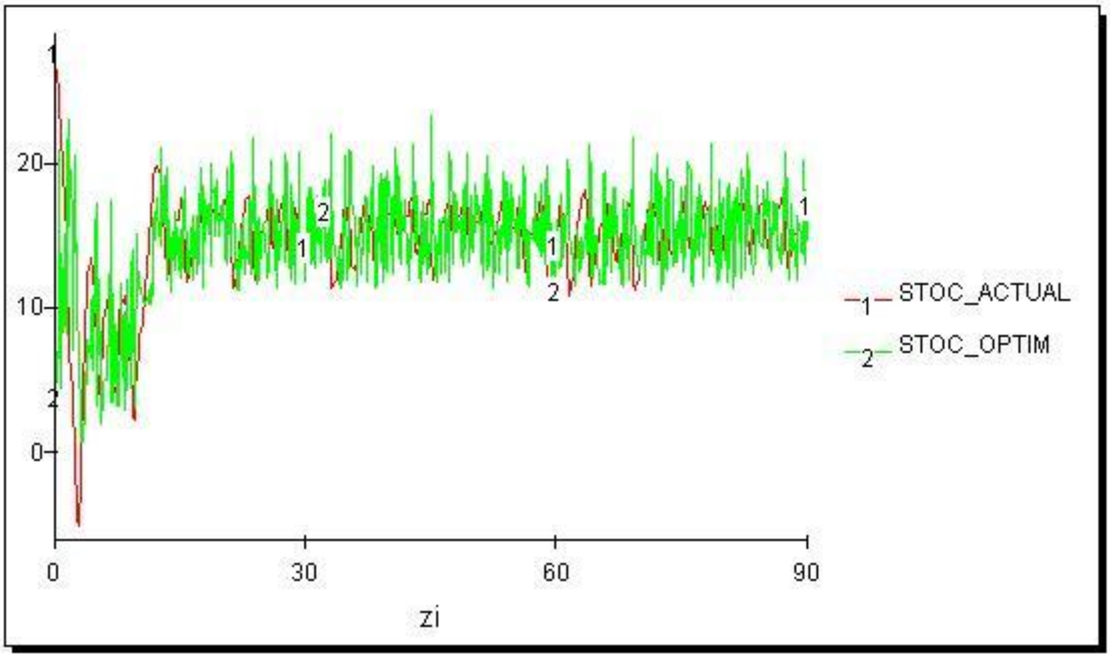


Figure 23 The fluctuations of controlled variable for *„mici''*

3.5.4 Economic efficiency proving of the Fuzzy Expert System implementation

Expected profit=15,3lei*15kg–10,8*18kg+5lei*4,225kg–(15,3+6lei)*1,225kg =30,14≈30lei

Simulated profit =17lei*15kg–10,8lei*17kg+5lei*3,6kg–(17+6lei)*1,6kg=52,6≈53lei

The implementation of Fuzzy Expert System ensures a 77 percent relative profit growth.

3.6 Case study of ''salam italian'' product in Transeuro store

3.6.1 Performance evaluation of ''salam italian'' product

The real rate of stock turnover is above 9 percent acceptable rate that takes into account economic order quantity calculated mathematically (56kg) in the case of „salam italian'' inventory.

3.6.2 Fuzzy system implementation for inventory regulation of ''salam italian''product

Table 13 The parameters of e(t) FES input for „salam italian''

Funcţia / S^*=8kg	μ_{NR} $(-\frac{S*}{2}, -\frac{3S*}{8}, -\frac{S*}{4})$	μ_{NS} $(-\frac{3S*}{8}, -\frac{S*}{4}, 0)$	μ_{ZE} $(-\frac{S*}{8}, 0, \frac{S*}{8})$	μ_{PS} $(0, \frac{S*}{4}, \frac{3S*}{8})$	μ_{PR} $(\frac{S*}{4}, \frac{3S*}{8}, \frac{S*}{2})$
μ(e(t))	(−4, −3, −2)	(−3, −2, 0)	(−1, 0, 1)	(0, 2, 3)	(2, 3, 4)

Table 14 Second FES input parametrization for „salam italian''

Funcţia / S^*=8kg	μ_{NR} $(-S*, -\frac{3S*}{4}, -\frac{S*}{2})$	μ_{NS} $(-\frac{3S*}{4}, -\frac{S*}{2}, 0)$	μ_{ZE} $(-\frac{S*}{4}, 0, \frac{S*}{4})$	μ_{PS} $(0, \frac{S*}{2}, \frac{3S*}{4})$	μ_{PR} $(\frac{S*}{2}, \frac{3S*}{4}, S*)$
μ(∫e(t)dt)	(−8, −6, −4)	(−6, −4, 0)	(−2, 0, 2)	(0, 4, 6)	(4, 6, 8)

Table 15 FES output parametrization for „salam italian''

Funcţia / P_V=15,5lei	μ_{NR} $(-\frac{4PV}{10}, -\frac{3PV}{10}, -\frac{2PV}{10})$	μ_{NS} $(-\frac{3PV}{10}, -\frac{2PV}{10}, 0)$	μ_{ZE} $(-\frac{PV}{10}, 0, \frac{PV}{10})$	μ_{PS} $(0, \frac{2PV}{10}, \frac{3PV}{10})$	μ_{PR} $(\frac{2PV}{10}, \frac{3PV}{10}, \frac{4PV}{10})$
μ(∆p(t))	(−6, −4,5, −3)	(−4,5, −3, 0)	(−1,5, 0, 1,5)	(0, 3, 4,5)	(3, 4,5, 6)

3.6.3 Sistem simulation of ''salam italian'' product

Inventory model stabilization after 6 months simulation, at (6,58 kg, 21,46 lei).

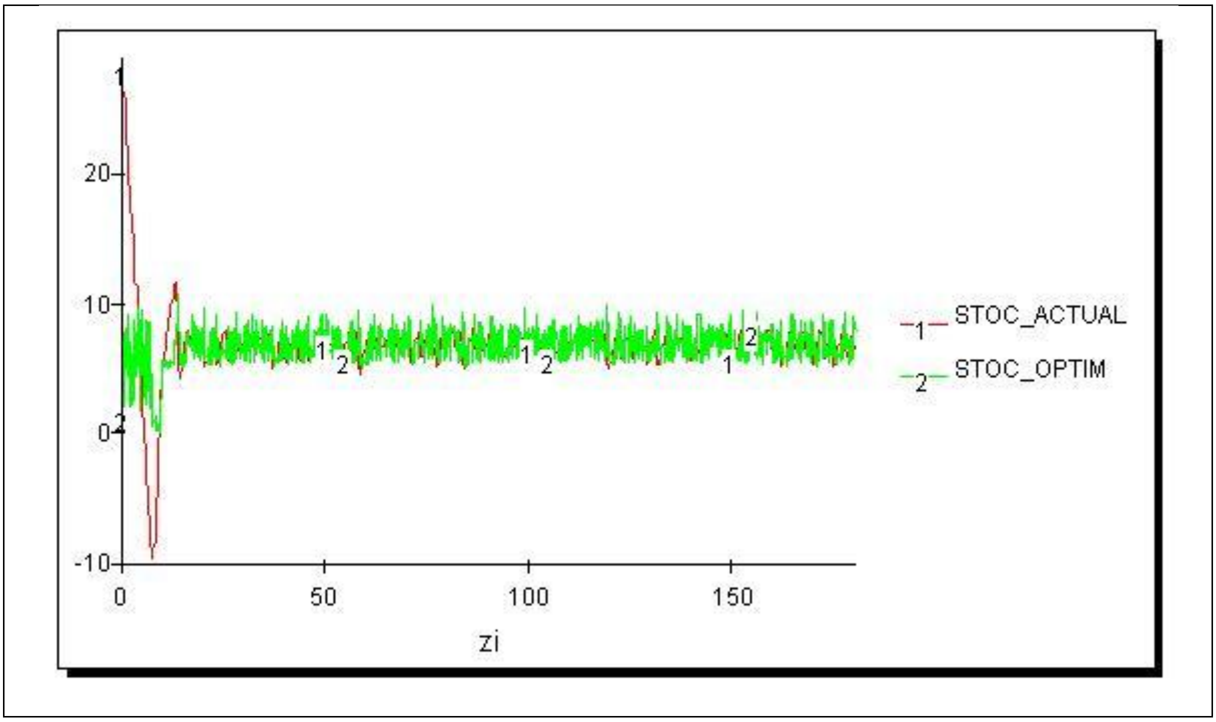


Figure 24 The 180 days simulation model for „salam italian'' inventory

In the 20th week, the oscillations are greatly diminished, then the negative feedback loop regulates the current stock at the optimum level; this operation is, in fact, the objective of the control system.

3.6.4 Economic efficiency proving of the Fuzzy Expert System implementation

Expected profit=15,5lei*6kg–10,8lei*8kg+8lei*2,25kg–(15,5+5lei)*0,25kg=*19,47lei*

Simulated profit=21,5lei*6kg–10,8lei*6,6kg+8lei*1,32–(21,5+5lei)*0,72kg

=49,2lei≈*49lei*

The implementation of FES ensures a 158 percent relative growth of profit by regulating ,,salam italian'' stock.

3.7 Case study of ''cârnaţ polonez'' product in Transeuro store

3.7.1 Evaluation of ''cârnaţ polonez'' product made in Transeuro

The real rate of stock turnover is above 18 percent acceptable rate

3.7.2 Fuzzy system implementation for ''cârnaţ polonez'' inventory regulation

Planning the optimal order for „cârnaţ polonez'', S^* is 10kg.

Table 16 Demand error input parametrization for „cârnaţ polonez''

Funcţia / S^*=10kg	μ_{NR} $(-\frac{S*}{2}, -\frac{3S*}{8}, -\frac{S*}{4})$	μ_{NS} $(-\frac{3S*}{8}, -\frac{S*}{4}, 0)$	μ_{ZE} $(-\frac{S*}{8}, 0, \frac{S*}{8})$	μ_{PS} $(0, \frac{S*}{4}, \frac{3S*}{8})$	μ_{PR} $(\frac{S*}{4}, \frac{3S*}{8}, \frac{S*}{2})$
μ(e(t))	(−5, −3,75, −2,5)	(−3,75, −2,5, 0)	(−1,25, 0, 1,25)	(0, 2,5, 3,75)	(2,5, 3,75, 5)

Table 17 The parameters of the integral of error for „cârnaţ polonez''

Funcţia / S^*=10kg	μ_{NR} $(-S*, -\frac{3S*}{4}, -\frac{S*}{2})$	μ_{NS} $(-\frac{3S*}{4}, -\frac{S*}{2}, 0)$	μ_{ZE} $(-\frac{S*}{4}, 0, \frac{S*}{4})$	μ_{PS} $(0, \frac{S*}{2}, \frac{3S*}{4})$	μ_{PR} $(\frac{S*}{2}, \frac{3S*}{4}, S*)$
$\mu(\int e(t)dt)$	(−10, −7,5, −5)	(−7,5, −5, 0)	(−2,5, 0, 2,5)	(0, 5, 7,5)	(5, 7,5, 10)

Table 18 The FES output parametrization for „cârnaţ polonez''

Funcţia / P_V=12lei	μ_{NR} $(-\frac{4PV}{10}, -\frac{3PV}{10}, -\frac{2PV}{10})$	μ_{NS} $(-\frac{3PV}{10}, -\frac{2PV}{10}, 0)$	μ_{ZE} $(-\frac{PV}{10}, 0, \frac{PV}{10})$	μ_{PS} $(0, \frac{2PV}{10}, \frac{3PV}{10})$	μ_{PR} $(\frac{2PV}{10}, \frac{3PV}{10}, \frac{4PV}{10})$
$\mu(\Delta p(t))$	(−4,8, −3,6, −2,4)	(−3,6, −2,4, 0)	(−1,2, 0, 1,2)	(0, 2,4, 3,6)	(2,4, 3,6, 4,8)

3.7.3 System simulation of ''cârnaţ polonez'' product

The inventory model balance after 90 days is (9,33 kg, 15,74 lei).

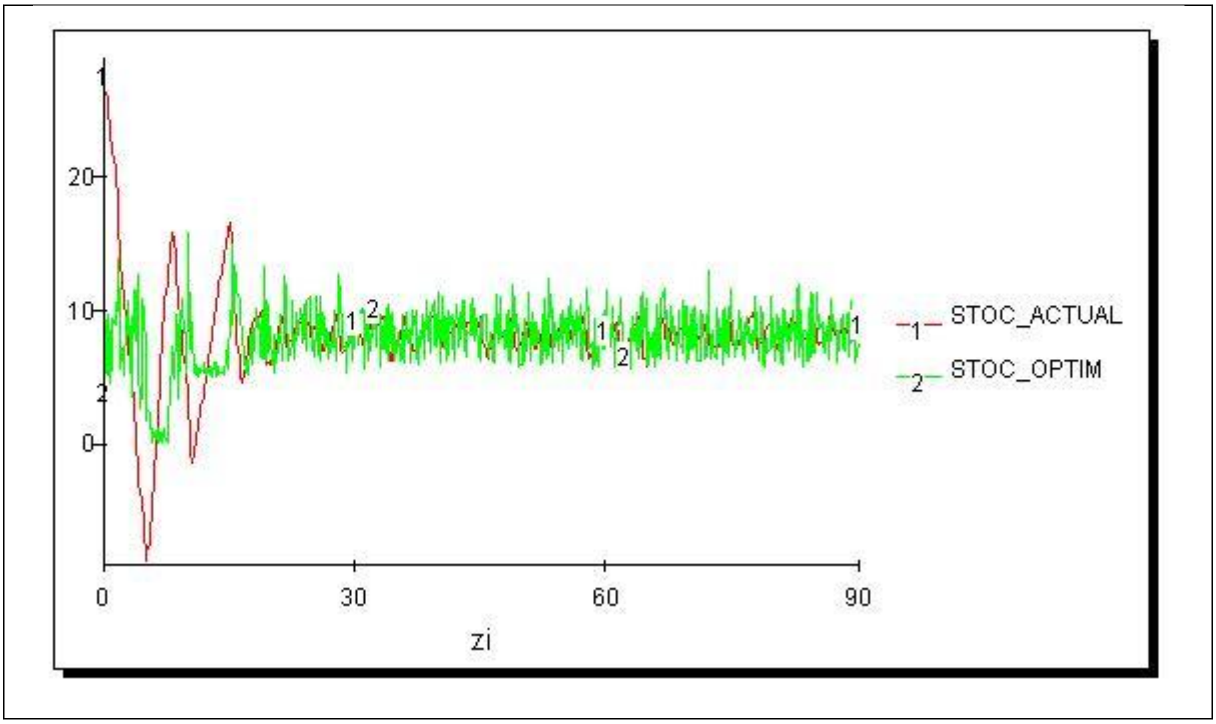


Figure 25 Fluctuations on 90 days of controlled variable „cârnaţ polonez'' actual inventory

3.7.4 Economic efficiency proving as result of Fuzzy Expert System implementation

Expected profit=12lei*9kg–8,2lei*10kg+3lei*2,04kg–(12+4lei)*1,04kg=15,48*lei*

Simulated profit=15,7lei*9kg–8,2lei*9,3kg+3lei*1,65kg–(15,7+4lei)*1,35kg; (Ecuaţia 3.9)

=43 lei

The application of FES provides a 169 percent relative growth of profit.

3.8 Case studies conclusions

We started with the performance evaluation of inventory product. I compared the rate of inventory turnover indicator with the acceptable rate and found differences. These differences, I felt that translate into a delay in recovering capital invested in stocks, i.e. the firm is paid late. Hence, the need to improve the economic efficiency through the implementation of a control /inventory optimization.

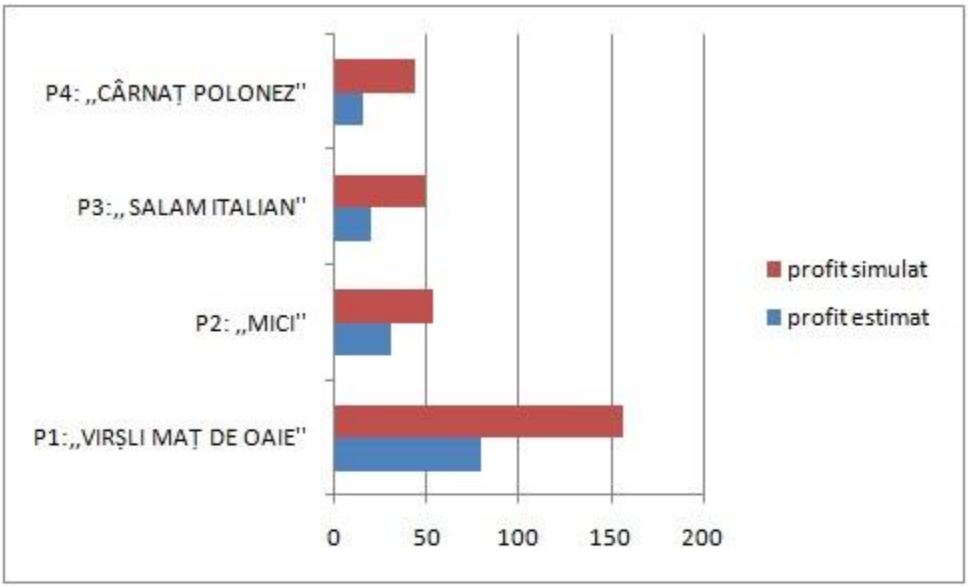


Figure 26 Comparing the relative economic efficiency of the products studied

Table 19 Comparative analysis of the economic efficiency

Profit / Products	Estimated Profit [lei]	Simulated Profit [lei]	Relative Growth [%]
''Virșli maț de oaie''	79	157	99%
''Mici''	30	53	77%
''Salam italian''	19	49	158%
''Cârnaț polonez''	16	43	169%

From the analysis of the relative increase profits, we see an average increase of 126% of the economic performance for the studied products, as a result of implementing the Fuzzy Expert System. Thus, economic efficiency is demonstrated.

On the other hand, from the customer point of view, the inventory performance indicator for the meat preparations (that are highly perishable products) is ,,stock age" or more precisely product freshness. By implementing the proposed system, this important benefit for the customer is insured, i.e. the delivery of fresh product at the right price.

PART IV: CONCLUSIONS

4.1 General conclusions

I structured the information and the methodology of this thesis in four distinct parts:

- Reference state analysis of classical and hybrid Expert Systems and inventory management theory;
- Metodologia: a) four research hypotheses set-up, b) specialty literature investigation– State-of-The-Art, c) Expert Systems application cases analysis in inventory management, and d) the sysnthesis in order to develop an improved model;
- Original Fuzzy Expert System development with the help of Fuzzy Lite 3.1 tool, and
- Proposed model testing: a) through four case studies of Transeuro products, and b) by using a dynamic simulation model developed with PowerSim 2.51 tool.

each of them with clearly defined research goals: defining the problem, clarifying the research directions, analyzing the strengths and weaknesses of the FES models implemented in inventory management, the synthesis in order to propose an improved system, and validation through case studies and simulation.

By considering the decision-making as the main task of an expert, the FES proposed in the present thesis is:

- an (Intelligent) System for improving the decision making – in general, and
- a Fuzzy Expert System for planning/control/optimize of the finished goods inventory – in particular.

The proposed Fuzzy Expert System has a rather **assistant expert status**, than the expert himself as it takes approximately 80 % of transactions for the purpose of relieving expert inventory management of the relatively routine and time consuming operations , in order for him to focus on the creative 20 percent of assets, according to the principle of 80/20 (Pareto)

In the creative approach we started from a typical soft computing approach , namely inverted pendulum stabilization using seven type fuzzy rule "if - then" performed by Takeshi

Yamakawa in 1989 (different from the traditional method involving calculating differential equations). This example was the source of inspiration for developing the hybrid model - proposed in this thesis, i.e. Fuzzy Expert System for inventory control of finished goods developed in the Fuzzy Lite 3.1 software.

The inventory control model is designed as probabilistic single cycle of the purchase order, meaning that the replenishment decision does not depend on the previous ones, and is based on minimizing the estimated costs. Production scheduling is based on the daily demand forecast, forecast that is based on a uniform/rectangular distribution function. The latter is well suited to the goods (in our case - fresh meat products) sold in bulk [kg] because it gives an equal probability to all quantities, in a request frame with known boundaries. Moreover, in the simulation, this rectangular distribution can be modeled firsthand (with preset function RANDOM). The drawback of this approach is that in practice it must be corrected by human experts, because - according to Johnston et al. (2003, p. 836) - the request is merely a geometric distribution, characterized by increased probability for small quantities.

I used the probabilistic model with a single purchase order (single cycle of the order), which minimizes the expected costs (and not current ones) due to the possibility of using dynamic selling prices strategy (which can be changed several times per day for sale). This dynamic pricing is common in areas such as booking seats, hotel rooms reservations; these prices vary by day of week, season, etc.

Thus:

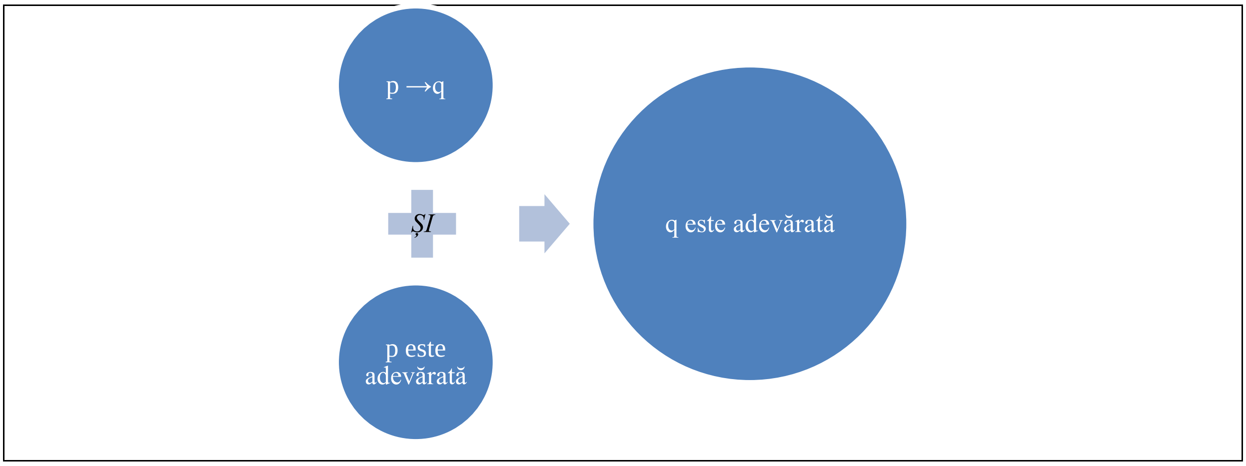


Figure 27 The presentation of the reasoning behind the research hypotheses

This type of inference is also known in logic (mathematics) under the name,, modus ponens ", and works as follows: given the implication of the premise (p) and conclusion (q), we just have to prove the validity of the premise (sentence p).

Limits of the model

The proposed model is based on a similar approach to scientific management (introduced as science F. Taylor), of capturing knowledge, prevailing scientific knowledge- (of works, textbooks, lectures) and endeavor to translate them into general rules. One of the most appropriate instruments for this is fuzzy logic.

However, we need to take into account the distinction between theoretical knowledge (science) and practical (empirical). In an elaborate and precise manner, Scott J.C. (1998, 2007 romanian translation, p. 384) distinguishes between the concepts ,,techne" and ,,mētis" saying that *techne* is "universal", "analytical", "de-buildable", "verifiable" and can be submitted formally and *mētis* is "contextual and particular", and refers to "personal competence" and «common sense».

Therefore, the rules are not static or fixed once and for all, but - with a dynamic character - is necessary their permanent adjusting to the new situations. Local knowledge and especially empirical rules for their application in dynamic situations is personal expertise (*mētis*) valuable asset of any specialist.

But this kind of knowledge, understood over time, experience shows that it can not be fully captured or fully mimicked by Expert Systems, even hybrid (fuzzy). Apprenticeship at work is invaluable, and man is responsible for the decisions taken. So, the system can not replace the expert himself, but it can relieve him of routine decisions, according to the principle of 80/20 (or Pareto).

Highly creative decisions, to be taken quickly in dynamic contexts relate to the so-called **gut-feeling** (flair, intuition) that differentiates managers/top experts from the others. Spiritual qualities, inherent in major decisions are human specific and are impossible to transmit the creations of artificial intelligence.

Regarding the range of the proposed system in this thesis, it is small, having implemented 25 rules and that required the work of months-person. The development software – Fuzzy Lite 3.1 (© Juan Rada-Vilela) of the FES was used for academic purposes and does not involve expenses. The important aspect is that it can be generalized to any type of stock control of finished product, with amendments and additions related mainly to capture human expertise of the management of that stock.

4.1.1 Results disemination

A – Indexed published scientific papers:

1. Stoia, C.L. (2013), *,,A Study Regarding the Use of Expert Systems in Economics Field''*, Procedia Economics and Finance, Volume 6, 2013, pp. 385–391, doi:10.1016/S2212-5671(13)00152-4;

2. Stoia, C.L. (2014), *,,An Analysis Regarding the Possibility of Using Fuzzy Logic in Inventory management''*, ACTA Universitatis Cibiniensis–Technical Series Vol. LXIV No 1 2014, DOI: 10.2478/aucts-2014-0014, DE GRUYTER OPEN;

3. Stoia, C.L. and Achim, I.M. (2015), *,,A synthesis regarding the application of Expert Systems in Inventory management'', 2015 IEEE International Conference on Industrial Technology (ICIT), 17-19 March 2015, Seville, pp. 2382 – 2387*, DOI: 10.1109/ICIT.2015.7125449;

4. Stoia, C.L. and Achim, I.M., *,,A Guide to Use Expert Systems in Inventory Management''*, *in press*, Polish Journal of Management Studies, 2015, indexat SCOPUS.

4.2 Own contributions

In presenting original contributions, we have followed the four important aspects of the structure of this thesis as follows:

- Defining the problem to be studied - as it is a matter of decision at a general level, and on a particular level, a problem of regulating planning + control +adjustement of production upon request, in order to optimize stocks of finished goods. Stock management is aimed at optimizing the stock, in a broad sense, including balancing the divergent interests on stock levels in an organization.
- Methodology (research design) -we have developed and proven four hypotheses that led to the proposed model. By the methods used: specialized literature investigation, analysis and synthesis of application cases, we have identified strengths and weaknesses of the existing relevant models in order to build an improved model.

- The design of the original model - I managed to identify the analogy between a fuzzy control classic problem - to stabilize an inverted pendulum, settled in 1989 by Professor Takeshi Yamakawa using the seven rules fuzzy if-then and the problem of controlling the stock of finished products using the selling price manipulated variable, the controlled variable being ACTUAL INVENTORY, which must match TARGET_INVENTORY (the forecasted level of the order / batch based on a probabilistic model of the stock with a single command, the demand is distributed rectangularly).

I combined / integrated the dynamic model of supply and demand proposed by Whelan, J. & Msefer, K. (1996, p. 20) and model presented in the Guided Study Program in the MIT System Dynamics (1999, p. 4) and I adapted them in order to build a simulation model for the use of testing the proposed fuzzy expert system. Own **adaptation** of the two models consisted of:

a) I modeled the variable PRODUCTION_ON_PRICE with a chart function to economically substantiate the variation of selling price in order to use it as a tool to regulate stock (optimization);

b) I have formulated differentely OPTIMAL_STOCK, as a produce between demand and customer service level (eg. 98%);

c) I modeled the *NORMAL DEMAND* variable: initially being constant, I substituted it with a RANDOM () function corresponding to a uniform/rectangular distribution with minimum and maximum known limits;

d) I have developed the model in a third software - PowerSim 2.51; inspiring models being built in STELLA, respectively Vens software;

e) I initiated the simulation with the data corresponding to the proposed fuzzy expert system for testing.

- Testing the model - I made it through: a) four case studies of four meat products, produced and retailed through the integrated value chain of SC Transeuro Grup Ighiu (founded 1991), an important producer on the regional and national market, and b) through simulation in address Forrester techniques/ industrial dynamics I have demonstrated the economical efficiency of the implementation FES proposed.

4.3 New proposals

Taking into account the two aspects of differentiation above, our aim is to continue research on two research directions having unity and continuity, thus:

- **The intensive path** - regarding the deep study of hybrid methods for knowledge representation for the application of Expert Systems technology, whether they are systems or shells for building ES.

  A. The theoretical part: representation by fuzzy logic method has reached an such an advanced stage so that it processes complex sentences, not just words. It is the implementation level 2 of C. W. - Computing with Words. Curiosity prompts us to know the stage of development of this soft computing area (including neural networks and genetic algorithms) that if it has reached the science stage, or just the level of consensus upon the principles of application.

  B. The Application part: The most relevant application to the inventory in the light addressed in this thesis, diffuse (fuzzy) controlling, has also reached level 2. It is interesting to study what improvements and what facilities these superior fuzy control systems can provide in inventory management.

- **Extensive research route -** regarding the study of the principles of combining expert system with conventional programming . The benefit of this pathway could be the development of a more friendly GUI and adding an explanatory module to the Fuzzy Expert System for the management of stocks of finished products proposed in this Phd thesis.

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