



# An Expert System for Planning and Designing Concrete Structures for Horizontal Silos

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# Introduction

- **Horizontal silos are built of concrete, provide storage at considerably lower costs, and are adaptable to self feeding**
- **Reinforced concrete is obtained by adequately mixing in specific proportions aggregates (gravel and sand), cement, and water**
- **Water:cement ratio is 0.53 l/kg and cement:sand:gravel mass ratio is 1:2.2:3.7 (Lindley and Whitaker, 1996)**



# Introduction

## Objectives



The objective is to develop a tool to:

- **design concrete horizontal silos**
- **compute the required amounts of construction materials**
- **calculate capital investment and fixed, variable, and total costs**



# Methodology

- A mathematical model was developed to design horizontal silos
- An electronic spark map was developed using MS-Excel
- The mathematical model was then integrated into the spark map
- C# was used to develop a software via the spark map
- Model validation was carried out using data of 4 horizontal silos
- COV and  $\sigma$  were calculated

# Methodology

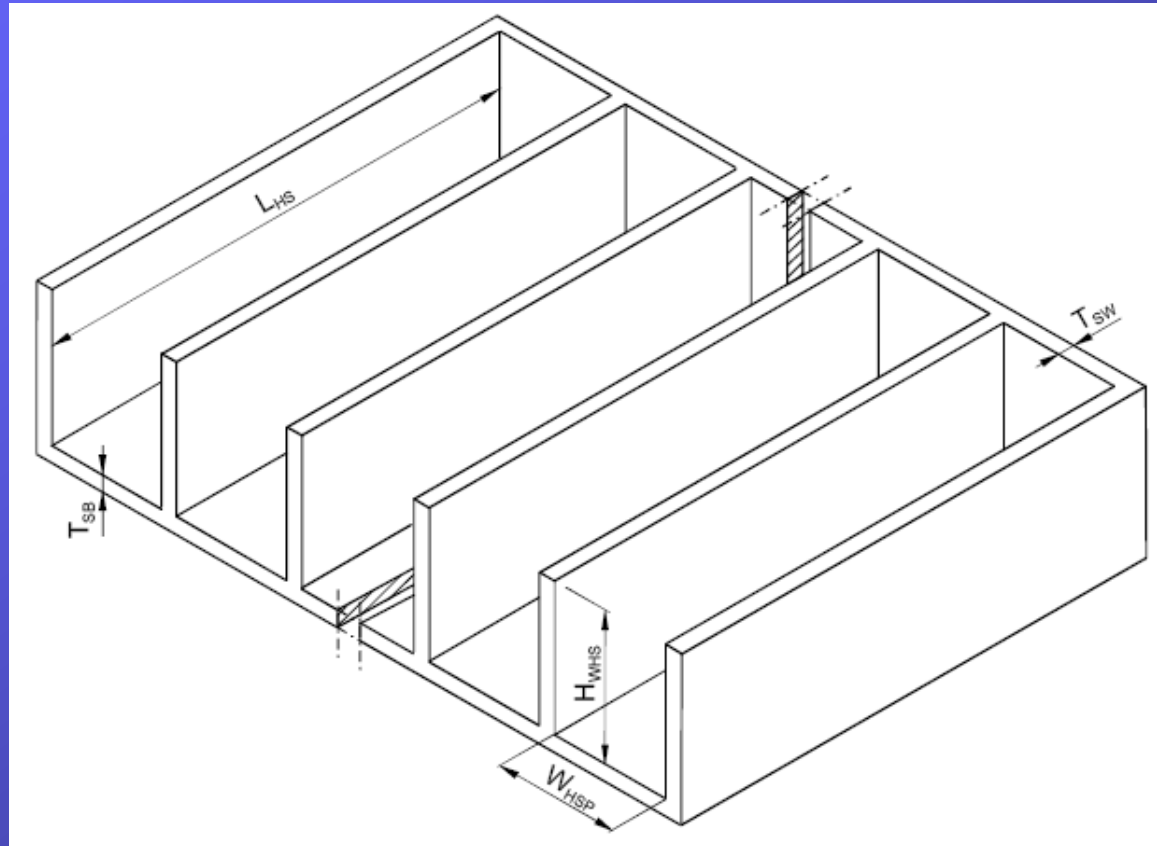
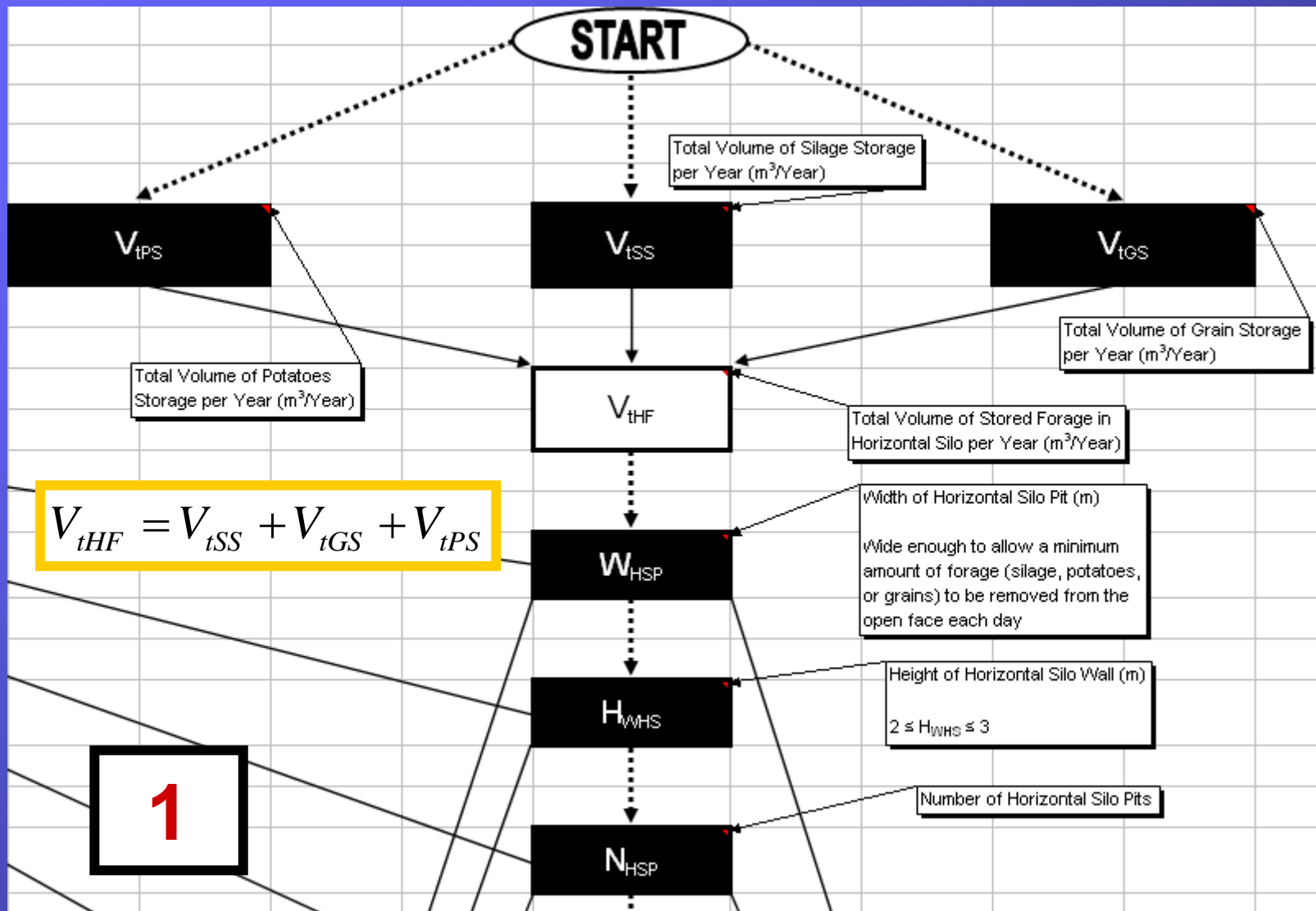


Figure 1: Concrete Horizontal Silo



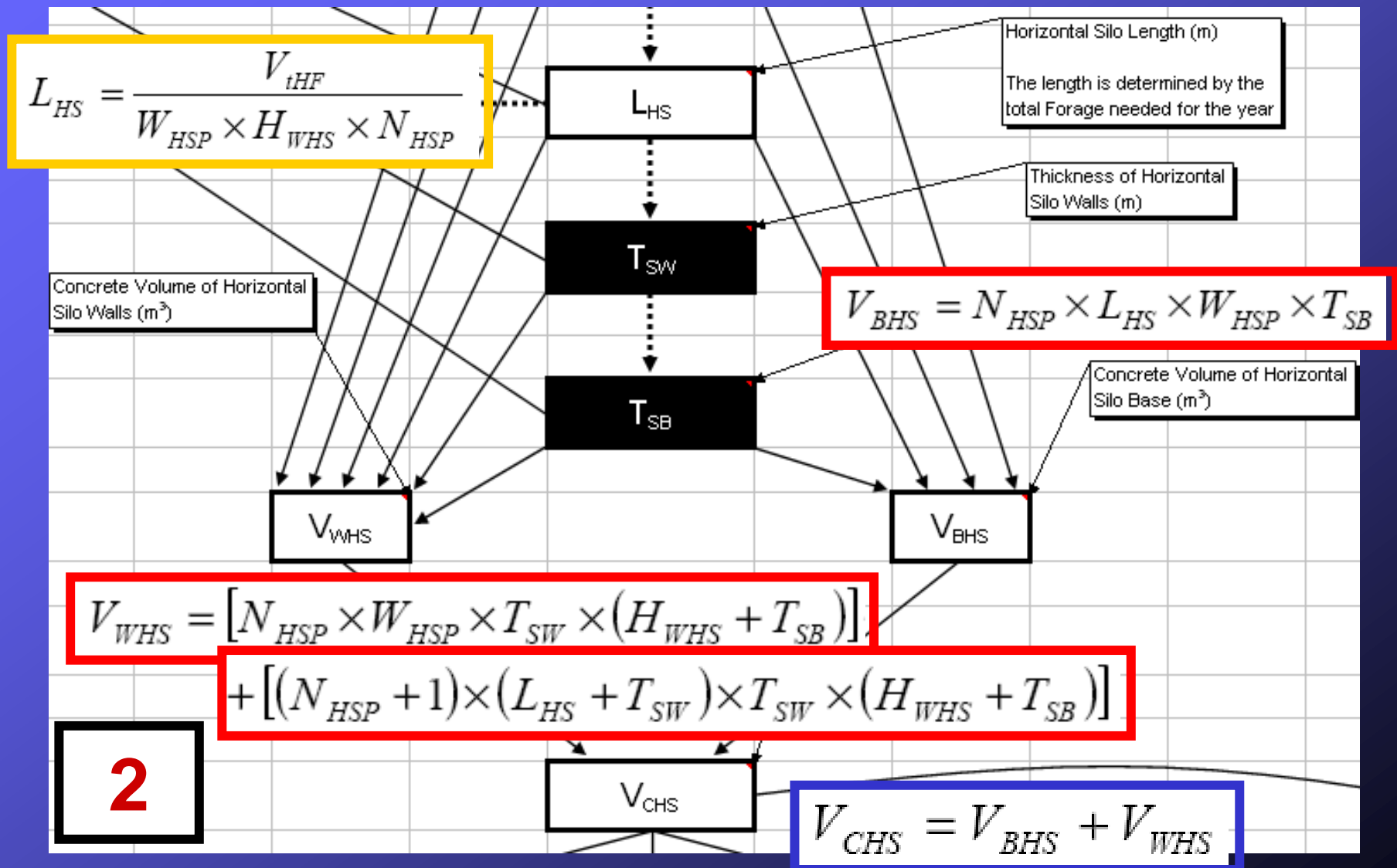
# Results and Discussion

## Mathematical Model



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## Mathematical Model





# Results and Discussion

## Mathematical Model

if  $N\phi D / m = 6\phi 6 / m$ ,  $M_{IML} = 0.666$

if  $N\phi D / m = 6\phi 8 / m$ ,  $M_{IML} = 0.888$

Number of Iron Rods per One Meter Length of Concrete

$N_{IML}$

Type of Iron Rods

$N\phi D / m$ :  
6 $\phi$ 6/m  
6 $\phi$ 8/m

1

$$N_{IW} = [(N_{IML} \times L_{PHS}) + 1] \times 1.05 \times W_{PHS}$$

Number of Iron Rods in Length

$N_{IL}$

$N_{IW}$

Number of Iron Rods in Width  
The standard iron rods are cut to shorter iron rods with a length of 1m, they are then used to build up the concrete base. Thus, the iron rod here has a width of 1 m.

$$N_{IL} = [(N_{IML} \times W_{PHS}) + 1] \times 1.05 \times L_{PHS}$$

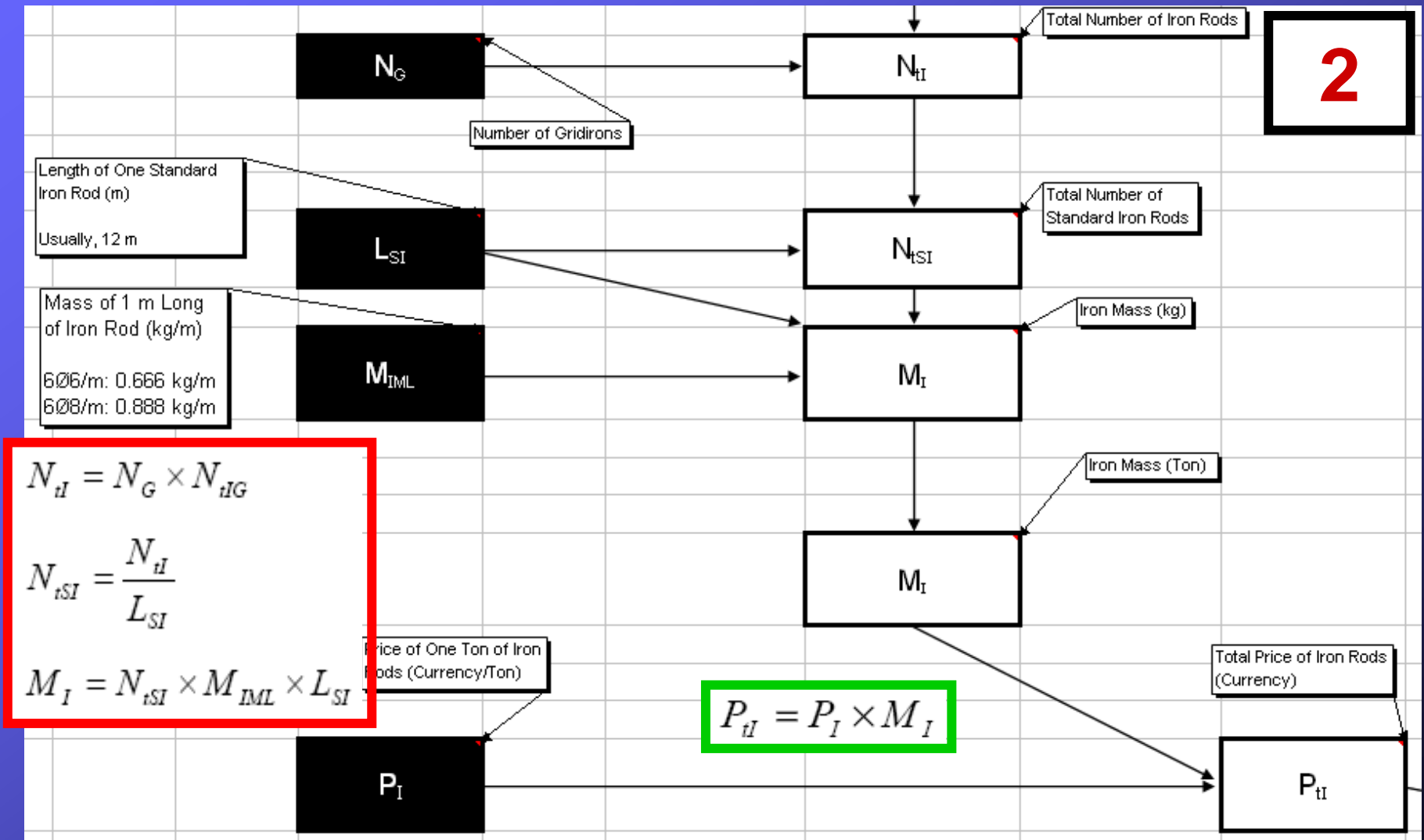
Total Number of Iron Rods in One Gridiron

$N_{IG}$

$$N_{IG} = N_{IL} + N_{IW}$$

# Results and Discussion

## Mathematical Model



# Results and Discussion

## Electronic Spark Map

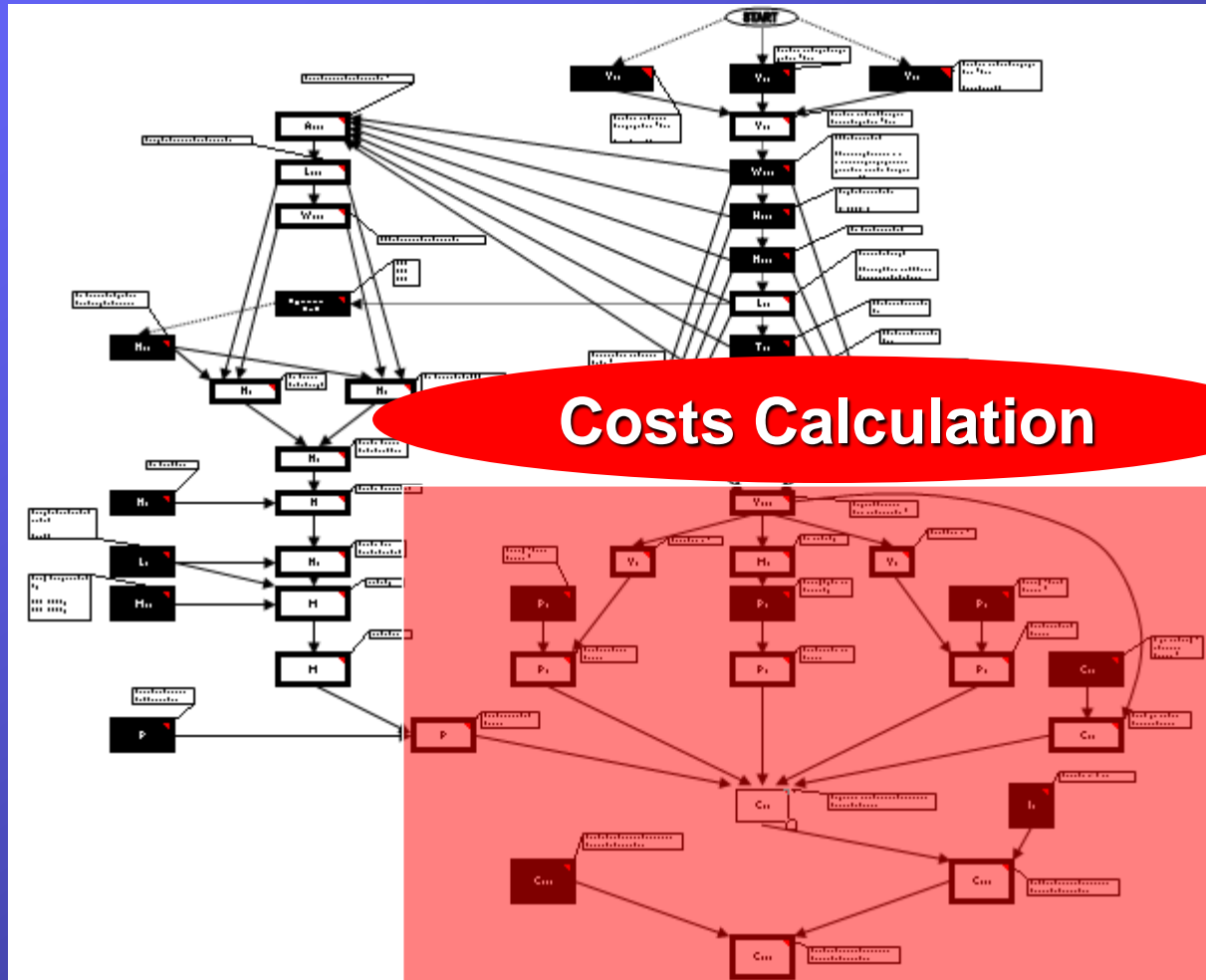
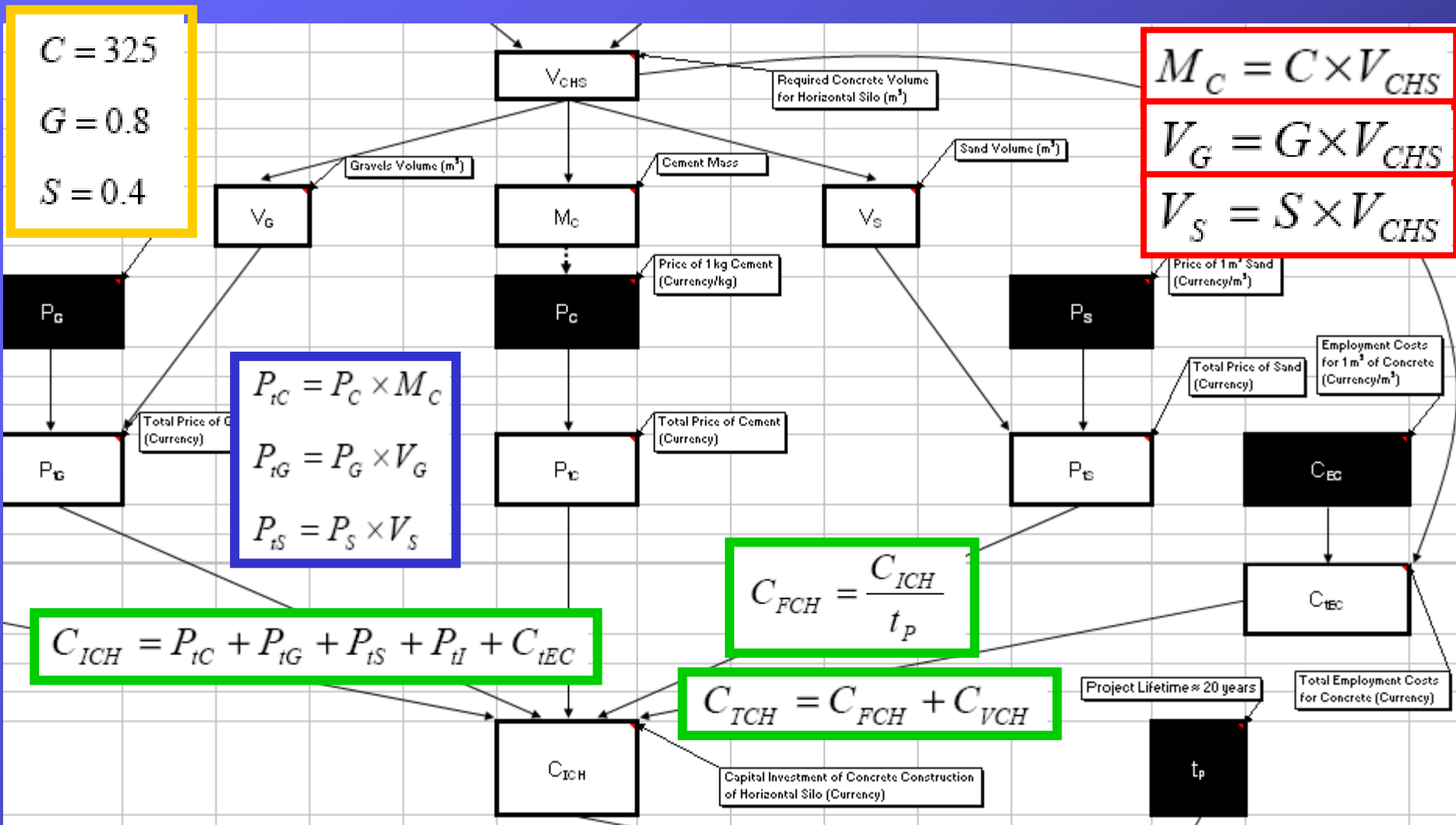


Figure 2: Electronic Spark Map

# Results and Discussion

## Mathematical Model





# Results and Discussion

## Computer Software

**Forage Storage Constructions Sub-Model - Part 3**

**Forage Storage Constructions Sub-Model: Horizontal Silo**

Total Volume of Potatoes Storage per Year	<input type="text" value="240"/>	m <sup>3</sup> /Year	Number of Iron Rods per One Meter Length of Concrete	<input type="text" value="6"/>	Rod(s)
Total Volume of Silage Storage per Year	<input type="text" value="3240"/>	m <sup>3</sup> /Year	Number of Gridirons	<input type="text" value="1"/>	Gridirons
Total Volume of Grain Storage per Year	<input type="text" value="312"/>	m <sup>3</sup> /Year	Length of One Standard Iron Rod	<input type="text" value="12"/>	m
Width of Horizontal Silo Pit	<input type="text" value="5"/>	m	Mass of 1 m Long of Iron Rod	<input type="text" value="0,67"/>	kg/m
Number of Horizontal Silo Pits	<input type="text" value="15"/>		Price of One Ton of Iron Rods	<input type="text" value="2800"/>	Currency/Ton
Height of Horizontal Silo Wall (2 - 3)	<input type="text" value="2"/>	m	Price of 1 m <sup>3</sup> Gravels	<input type="text" value="25"/>	Currency/m <sup>3</sup>
Thickness of Horizontal Silo Walls	<input type="text" value="0,2"/>	m	Price of 1 kg Cement	<input type="text" value="0,3"/>	Currency/Kg
Thickness of Horizontal Silo Base	<input type="text" value="0,2"/>	m	Price of 1 m <sup>3</sup> Sand	<input type="text" value="60"/>	Currency/m <sup>3</sup>
Type of Iron Rods <input checked="" type="radio"/> 6Ø6/m <input type="radio"/> 6Ø8/m			Employment Costs for 1 m <sup>3</sup> of Concrete	<input type="text" value="25"/>	Currency/m <sup>3</sup>
Volume of Required Gravels for Making 1 m <sup>3</sup> Concrete	<input type="text" value="0,8"/>	m <sup>3</sup> /m <sup>3</sup>	Variable Costs of Concrete Construction of Horizontal Silo	<input type="text" value="0"/>	Currency/Year
Mass of Required Cement for Making 1 m <sup>3</sup> Concrete	<input type="text" value="325"/>	kg/m <sup>3</sup>	Project Lifetime	<input type="text" value="20"/>	Year
Volume of Required Sand for Making 1 m <sup>3</sup> Concrete	<input type="text" value="0,4"/>	m <sup>3</sup> /m <sup>3</sup>	<input type="button" value="Calculate"/> <input type="button" value="Save"/> <input type="button" value="Close"/> <input type="button" value="Next &gt;&gt;"/>		
Wizard <input type="button" value=" &lt;&lt; Previous"/>					

Figure 3: Input data window of horizontal silo

# Results and Discussion

## Computer Software

Forage Storage Constructions Sub-Model - Part 3

**Forage Storage Constructions Sub-Model: Horizontal Silo**

Total Volume of Potatoes Storage per Year: 240 m<sup>3</sup>/Year  
 Total Volume of Silage Storage per Year: 3240 m<sup>3</sup>/Year  
 Total Volume of Grain Storage per Year: 312 m<sup>3</sup>/Year  
 Width of Horizontal Silo Pit: 5 m  
 Number of Horizontal Silo Pits: 15  
 Height of Horizontal Silo Wall (2 - 3): 2 m  
 Thickness of Horizontal Silo Walls: 0.2 m  
 Thickness of Horizontal Silo Base: 0.2 m

Type of Iron Rods:  
 606/m  608/m

Number of Iron Rods per One Meter Length of Concrete: 6 Rod(s)  
 Number of Gridirons:  
 Length of One Standard Iron Rod:  
 Mass of 1 m Long of Iron Rod:  
 Price of One Ton of Iron Rods:  
 Price of 1 m<sup>3</sup> Gravels:  
 Price of 1 kg Cement:  
 Price of 1 m<sup>3</sup> Sand:  
 Employment Costs for 1 m<sup>3</sup> of Concrete:  
 Variable Costs of Concrete Construction of Horizontal Silo:  
 Project Lifetime:

Volume of Required Gravels for Making 1 m<sup>3</sup> Concrete: 0.8 m<sup>3</sup>/m<sup>3</sup>  
 Mass of Required Cement for Making 1 m<sup>3</sup> Concrete: 325 kg/m<sup>3</sup>  
 Volume of Required Sand for Making 1 m<sup>3</sup> Concrete: 0.4 m<sup>3</sup>/m<sup>3</sup>

Buttons: Calculate, Save, Close, New, Wizard, << Previous

Figure 3: Input data window of horizontal silo

**Forage Storage Constructions Sub-Model: Horizontal Silo**

Forage Storage Constructions Sub-Model: Horizontal Silo

Item	Result
Total Volume of Stored Forage in Horizontal Silo per Year	3792 m <sup>3</sup> /Year
Horizontal Silo Length	25,28 m
Concrete Volume of Horizontal Silo Walls	212,38 m <sup>3</sup>
Concrete Volume of Horizontal Silo Base	379,2 m <sup>3</sup>
Required Concrete Volume for Horizontal Silo	591,58 m <sup>3</sup>
Gravels Volume	473,26 m <sup>3</sup>
Cement Mass	192263,24 kg
Sand Volume	236,63 m <sup>3</sup>
Area of Concrete Plot of Horizontal Silo	2825,9 m <sup>2</sup>
Length of Concrete Plot of Horizontal Silo	53,16 m
Width of Concrete Plot of Horizontal Silo	53,16 m
Number of Iron Rods in Length	17858,96
Number of Iron Rods in Width	17858,96
Total Number of Iron Rods in One Gridiron	35717,92
Total Number of Iron Rods	35717,92
Total Number of Standard Iron Rods	2976,49
Iron Mass	23,93 Ton
Total Price of Iron Rods	67006,83 Currency
Total Price of Gravels	11831,58 Currency
Total Price of Cement	57678,97 Currency
Total Price of Sand	14197,9 Currency
Total Employment Costs of Concrete	14789,48 Currency
Capital Investment of Concrete Construction of Horizontal Silo	165504,76 Currency
Fixed Costs of Concrete Construction of Horizontal Silo	8275,24 Currency/Year
Total Costs of Concrete Construction of Horizontal Silo	8275,24 Currency/Year

Buttons: OK

Figure 4: Output data window of horizontal silo



# Results and Discussion

## Validation and Evaluation



**Table 1: Data of 4 concrete horizontal silos**

	Parameter	$V_{CHS}$	$V_G$	$M_C$	$V_S$	$M_T$
Silo 1	Actual Value	600.3	479.2	193.2	240	24.17
	Calculated Value	594.2	475.4	193.1	237.7	23.92
Silo 2	Actual Value	732	585	235.8	292.5	29.49
	Calculated Value	725.2	580.1	235.7	290.1	29.21
Silo 3	Actual Value	972.5	776	313.1	389	33.35
	Calculated Value	962.9	770.3	312.9	385.2	33.04
Silo 4	Actual Value	100.9	80.6	32.5	40.4	3.82
	Calculated Value	99.9	79.9	32.5	39.9	3.78

→ COV ranges between 3.4% and 7.3%

→ The system's accuracy is 98%



# Conclusions

- **Most mathematical models can be developed as spark maps in order to simplify their use for practical implementation**
- **The spark map can be then instantly used to make calculations, and to get automatically the results of the input settings**
- **Spark map (semi-automatic system) → back diagram code of the computer software (automatic system)**



# Summary

- **A mathematical model and a spark map were developed**
- **The mathematical model is then integrated into the spark map**
- **A computer software was developed using C# language**
- **Data of 4 concrete horizontal silos were used to carry out the model validation and evaluation**



# Perspective

→ The main models were developed:

1. Design Model
2. Costs Calculation Model

→ Additional sub-models were developed:

- Concrete Base
- Forage Storage
- Manure Tanks
- Farm Planning
- Cooling System
- Water Consumption and Sources
- Electricity Consumption and Sources
- Roof Materials & Structures
- Milking Parlor Constructions
- Biogas Plant Constructions

→ Expert System Configuration

**Thank  
You !**



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