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How to support group decision making in horticulture: An approach based on the combination of a centralized mathematical model and a Group Decision Support System

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Abstract. Decision making for farms is a complex task. Farmers have to fix the price of their production but several parameters have to be taken into account: harvesting, seeds, ground, season etc… This task is even more difficult when a group of farmers must make the decision. Generally, optimization models support the farmers to find no dominated solutions, but the problem remains difficult if they have to agree on one solution. In order to support the farmers for this complex decision we combine two approaches. We firstly generate a set of no dominated solutions thanks to a centralized optimization model. Based on this set of solution we then used a Group Decision Support System called GRUS for choosing the best solution for the group of farmers. The combined approach allows us to determine the best solution for the group in a consensual way. This combination of approaches is very innovative for the Agriculture domain.

Keywords: Centralized Optimization Model, Group Decision Support System, AgriBusiness.

1 Introduction

Fixing the price of farms products is always a hard decision. The real food prices are determined by the food supply-demand balance [1]. The price to be determined is generally function on demand but also on supply [2]. Farmers usually select which crops to plant in function of the expected benefits that will be produced. Nevertheless, if all farmers decide to plant the same crops, this would result in a decrease of the crop's sales price, turning it less profitable. Simultaneously, the supply of less profitable crops would be lower than their demand, resulting in an increase of their final sales price and, therefore, in their conversion into more profitable crops. It is then mandatory to effectively match demand and supply in the agri-food supply chain processes [3]. The remaining question is then, how can farmers decide which crops to cultivate each season to maximize their profits?

It has been proved by [4] that one solution to this problem could be to centrally plan the planting and harvest for all the farmers while maximizing the profits of the region. However, this solution could produce inequalities in the profits obtained by farmers, leading to the unwillingness to cooperate.

In this paper, we aim to prove that making decisions for farmers using profitable information can lead to a better global decision. To achieve this objective, we used two technics: one coming from mathematical modelling and one coming from the Group Decision Support Systems. It has been proved by [4] it is more favorable to reach an optimal solution for the whole supply chain and then, share it between its members; that implies that the profits obtained by farmers can be maximized and the inequalities between them can be reduced when centrally planning the planting and harvest of crops. A centralized optimal solution is then used in this paper as the best solution for this problem. It will be the benchmark of our study. This information is used in the group decision-making process.

We aim to show how a group engaged in a decision-making problem is influenced by the information that is available. For this purpose, we developed an experimental study. This study is based on the combination of two methodologies. We firstly generated a list of alternatives thanks to mathematical centralized model and then we used a Group Decision Support System. Our main goal is to combine two approaches to generate a satisfactory solution for a group. The paper is organized as follows. In the next section, we describe the related works on the two used technics, i.e. the GDSS and mathematical modeling for used for agriculture or horticulture purpose. The third section we present the used centralized mathematical model. In the fourth section briefly describes the used GDSS called GRoUp Support (GRUS) [5]. In the fifth section we describe the experiment decomposed by three subsections: 1. description of the used scenario, 2. presentation of the obtained alternatives by the centralized mathematical model and 3. description of the second GRUS use. In the sixth section, we analyze the obtained results and we conclude the paper in the last section.

2 Related Work

2.1 Group Decision Support Systems for agriculture or horticulture

GDSS are designed to support a group engaged in a decision-making process. There are a lot of study on group creativity and [6] reported a study that is descriptive in nature and designed to generate hypotheses that will form the basis for future research in order to facilitate group creativity. The used application domain is generally business oriented.

Some studies report the design of DSS for agriculture. Recent approaches in building decision support systems (DSS) for agriculture, and more generally for environmental problems, tend to adopt a “systemic” approach [7] focus on design issues faced during the development of a DSS to be used by technicians of the advisory service performing pest management according to an integrated production approach. These last studies report on systems designed for single user and not for a group of decision makers.

Nevertheless, decisions to make are also a question of group of persons in the Agriculture domain. For example, when the products are ready to be sent the supply chain process involves a group of stakeholders: farmers, sellers, transporters, auctions persons. There is a need to develop a process and a support for a group engaged in a decision-making process in agriculture.

2.2 Collaborative planning for agriculture or horticulture

An increasing number of recent research works recognize the necessity of implementing collaboration mechanisms among the members of fruit and vegetable SCs for achieving sustainability [8], increase revenues and customer satisfaction and reduce the negative impact of uncertainty [9]. [10] distinguish three interrelated dimensions of collaboration: information sharing, decision synchronization, and incentive alignment. In the context of decision synchronization, we center on collaborative operations planning at the tactical level. Different literature reviews ([11]; [12]) conclude the shortage of research addressing collaborative planning issues in the agricultural sector and the scarce number of integrated planning models. When collaborative planning is implemented under a distributed approach, it is necessary to implement coordination mechanisms ([13]). [14] affirm that still, research on coordination-related issues in an agricultural supply chain is in its early development and not cover coordination of the whole supply chain. They state that studies on the coordination of processed fruits and vegetables products have been more widely studied than the coordination of fresh produce.

In their review, [14] also identify mathematical modelling as one methodology used in agri-food supply chain coordination. One application can be found in the work of [15] who propose a distributed mathematical model for the coordination of perishable crop production among small farmers and a consolidation facility using auction mechanisms. Another example is the research of [9] where a collaborative mathematical model is proposed to improve farmers' skill level by investments in an uncertain context.

[14] conclude in their review that studies on supply chain coordination in agri-food sector with a particular focus on small-scale farmers is very scarce. Besides, [16] highlight as a conclusion of their review that although quantitative modeling approaches have been applied to agricultural problems for a long time, adoption of these methods for improving planning decisions in agribusiness supply chains under uncertainty is still limited. [17] identify as new opportunities for operations research in agri-food SC better predictive modelling of the decision making behavior of actors in the natural resources system, multiple stakeholder decision analysis, optimization in a more complex business environment and multi-criteria decision making. [18] affirm that when dealing with the complexity of agri-food supply chain, sustainability is one of perspectives that can be applied to maintain the competitive strategies in economic,

environmental, and social aspects that is called triple bottom line. For that, multi-criteria or multi-objective decision support tools should be developed that take into account the three dimensions of sustainability. [19] propose hybrid-modelling approaches to cope with the complexity of real-world Sustainable Food SC in order to obtain managerial insights.

It can be drawn as a conclusion that research on coordination issues in agricultural SCs is in its early development. Moreover, research addressing coordination among actors in the same stage specifically at the farmer stage is even more scarce. In view of this, this paper analyses how the multi-criteria group decision-makingbehavior of small farmers supported by GRUS DSS is affected by the optimal solution knowledge obtained from a mathematical model. Three objectives (criteria) related to the economic, social and environmental categories are considered to achieve the sustainability of the horticulture supply chain coping, therefore, with the so-called triple bottom line. Therefore, with this work we contribute to fill the scarcity of works dealing with multiple stakeholder decision analysis, coordination among small farmers, predictive modelling of their decision-makingbehavior and application of hybrid modelling approaches to achieve the sustainability in horticulture SCs.

3 Mathematical Model for the tomato planning problem

A mixed integer linear programming model has been developed to support the centralized decision making about: the time and quantity of different types of tomato to be planted and harvested by different farmers, the quantity of each type of tomato to be transported from the farmer to each market as well as the unfulfilled demand for each type of tomato and market. The main reason for defining two different decision variables for planting and harvesting quantities stems from the fact that planting and harvesting time periods are different. Therefore, it is important to detail not only how much is harvested but also when it is harvested and put on the market in order to match the market demand at prices as high as possible. Due to the yield of fields in each period is an uncontrollable variable by farmers, it could happen that the quantity ready to be harvested per period was higher than the market demand. In this scenario, the farmer could decide not to harvest all the tomatoes that have matured in order to save additional costs. Based on this, the quantity of each type of tomato wasted at each period in each farm is derived.

The optimum value for the above decision variables in the the supply chain will depend on the specific input data and the objectives pursued. As regards the input data, the following information is required: the estimation of the selling price and the market demand for the different types of tomato and for each time period, the yield for each farmer and tomato type, the density of cultivation, the total area available for planting in each farm, the activities to be carried for each type of tomato and the resources consumed, the costs of labor, waste, transporting tomatoes and unfulfilled demand. Feasible dates to plant and harvest each tomato type are also necessary.

When making the above decisions the three dimensions of SC sustainability are taking into account by the definition of three conflicting objectives that give rise to a multi-objective model. These objectives are the following:

- Economic Objective: The first objective consists in maximizing the profits of the whole supply chain calculated as the sales incomes minus the total costs. These costs contemplate those incurred due to tomatoes production in each farm and the distribution from each farm to each market.
- Environmental Objective: The second objective aims at minimizing the total waste along the Supply Chain. The maximum profit does not necessarily imply the minimum waste: a famer can decide to plant a quantity of tomatoes in some specific periods that allow him to sell some quantity of tomatoes in the season with the highest prices. But this decision, that can imply the maximum profit, can also imply more waste because of the uncontrollable yield distribution. Therefore, the profit maximization and the waste minimization can be conflicting objectives. Because the minimization of the food loss and waste is one of the environmental sustainable objectives recognized in several studies and organisms such as FAO [20], we have introduced this objective in our model.
- Social Objective: The third objective tries to minimize the unfulfilled demand along all the Supply Chain covering human requirements and increasing the customer satisfaction.

The decisions made should respect the following constraints. The acreage for each type of tomato should not exceed the available planting area in each farm. It is necessary to ensure that all tomato types are planted in all planting periods. At the same time, it is required that all farmers plant tomatoes at all planting periods to ensure the flow of products. The maximum quantity to be harvested at each period should not be higher than the yield per unit area harvested. It is not possible to transport from each farmer to each market tomato quantities higher than those harvested in the same farm for each time period. The waste in each farm is calculated as the difference between matured tomatoes and those not harvested or transported. The balance equation for calculating the unfulfilled demand for each type of tomato and market is based on the difference between the market demand for each tomato type and the total quantity of this type of tomato transported from all farmers to the market. If more product was transported to markets than the necessary one to fulfil the demand, the exceeding tomatoes were wasted. The quantity of tomatoes that was finally sold could not exceed the supply nor the demand. Constraints are defined to ensure the coherence between the integer and binary variables related to the planting decision.

4 GRoUp Support (GRUS) description

The GRUS (GRoUp Support) system is a Group Decision Support System (GDSS) in the form of a web application developed on the GRAILS framework (an open source platform). GRUS can be used for making collaborative meetings where all participants are connected to the system at the same time or at different time; in the same location (room) or in different locations. GRUS requires an internet connection and provides classical functionalities of multi-user web applications (sign in/sign out, user management, etc.). With GRUS, a user can participate to several meetings at the same time. She/he can facilitate (animate) some of them and only participate as a standard user to other ones.

The GRUS system is based on collaborative tools, the main tools are: electronic brainstorming tools, clustering tools, vote tools, multi-criteria tool, etc. A collaborative process in GRUS corresponds to a sequence of collaborative tools. A collaborative meeting requires one facilitator, which can always contribute to the meeting.

A GRUS meeting is composed of two general steps: the meeting creation and the meeting achievement. In the meeting creation step, a user (usually the facilitator) defines the topic of the meeting, the facilitator, the group process, the beginning date and the duration. The facilitator can reuse an existing group process or can define a new one (see Fig. 1). In the second step (meeting achievement), the facilitator manages the meeting thanks to a toolbar (see Fig. 2). This toolbar is only available in the facilitator interface; other participants do not have it and just follow the group process. With this toolbar, the facilitator can: add/remove participants, go to the next collaborative tool, modify the group process and finish the meeting.

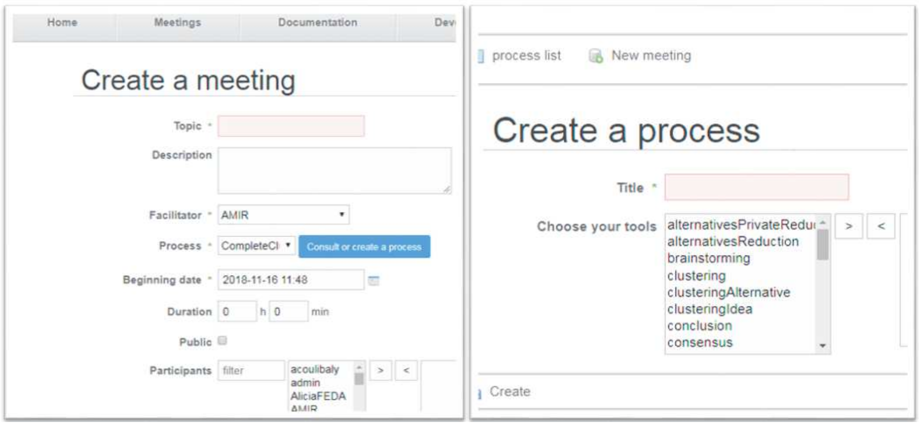


Fig. 1. Meeting and process creation

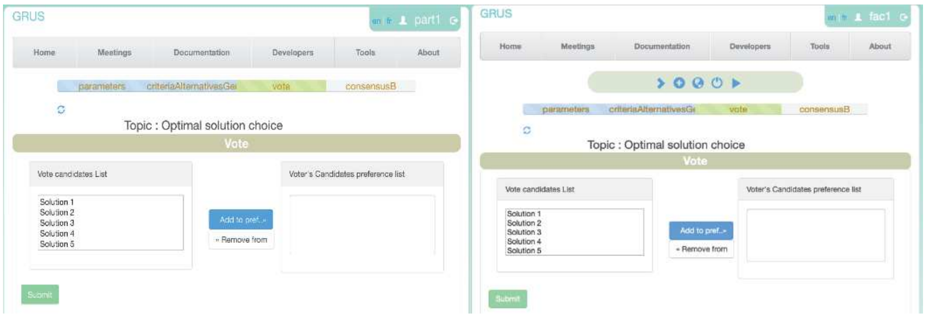


Fig. 2. On the left standard participant interface, on the right facilitator interface with the toolbar

5 Experiment

5.1 Scenario / Context

For the decision-making situation under study, we consider five farmers in the region of La Plata, Buenos Aires, Argentina, with an available planting area in hectare (ha) for each farmer of 20, 18, 17, 16 and 15, respectively. Our horizon is one year divided into monthly periods. Three types of tomatoes can be planted during three different months (July, October, and January) that do not depend on the specific type. The harvesting periods are the same for each type but depends on the planting period (Table 1). These planting periods are the usual in the region of La Plata, that is one of the most important areas of tomato in greenhouse for sell in fresh in Argentina.

Table 1. Harvesting periods

	07	08	09	10	11	12	01	02	03	04	05	06
July					X	X	X	X				
October							X	X	X	X		
January									X	X	X	X

During the growth of the plant from the planted date to the harvesting date, different activities need to be made to the plant in order to ensure its correct growth. These activities are called cultural practices. Each variety requires a different number of cultural practices at different time to perform each activity. Besides, one plant of each type of tomato can be harvested different number of times during the harvesting period and requires different time to harvest per plant. Both, the cultural practices and harvest activities, are made by laborers with limited capacity and with contracting costs.

The yield of the plant per month is dependent on the planting date and the type of tomato planted. The yield represents the kilograms (kg) of tomatoes that can be harvested per month from a single plant.

Once harvested the tomatoes are distributed to two different customers: a central market and some restaurants. The cost to transport one kg of tomatoes depends on the origin (farmers) and the destination (type of customer). The demand for each type of tomato is defined based on the month and market.

The price for each type of tomato also depends on the month in which it is sold. In addition, it is considered that sale prices vary in function of the balance between supply and demand. We estimate that prices increase when the total supply from all farmers is lower than demand. Prices decreases when the supply is higher than demand. In cases where some of the demand is not fulfilled because there is not enough supply (demand > supply), the benefit to be obtained is penalized with a cost. The penalization cost is calculated as ½ of the most probable price. Another penalization cost is included for cases in which some product is wasted throughout the supply chain (demand < supply). In its current state, the experiment does not take into account the fact that side payments would be possible to make the generated solution acceptable for all group members.

5.2 Results of the centralized mathematical model

To solve the multi-objective model, we transformed it into a single-objective model by applying the ε-constraint method ([21]; [22]). In this method, one of the objectives is selected as the model's objective function, while the other objectives are considered the model's constraints. The right-hand side (RHS) of these constraints are defined by the grid points (εi) that are obtained by dividing the objective's ranges of values into as many equal intervals as desired. The ranges of values that each objective modelled as a constraint can assume are determined by a lexicographic optimization proposed by [22].

Following this method, the model is optimized for one objective. Then, the model is optimized for a second objective by constraining the value of the first objective to its optimal value. The same process is made with the third objective by constraining both the first and second objective. When repeating the process for the different combinations of the objectives, a set of solutions is provided. Dominated solutions are discarded and non-dominated solutions are analyzed to identify the best and worst values for each objective. These values define the range of values used to define the grid points. Once the model is run for the different grid points combinations, solutions obtained do not necessarily have to be equally distributed in the objective's values.

For our case study, ten values were defined for the εi parameter. The model was implemented using the MPL software 5.0.6.114 and the solver Gurobi 8.0.1. This provide us with ten non-dominated solutions. The detail for each non-dominated solution can be consulted in Table 2 of Annex I. For each solution, the value of the three objective functions for the entire supply chain and for each farmer are presented. The area of land dedicated to each type of tomato in each farm are also reported. As it can be checked for the solutions reported, the profit, wastes and unfulfilled demand for each farmer varies with solutions and a solution that reports the best objective function for one farmer can be the worst for the other ones. Consequently, it is necessary a complementary procedure to decide which non-dominated solution to implement. This procedure is described in the following section.

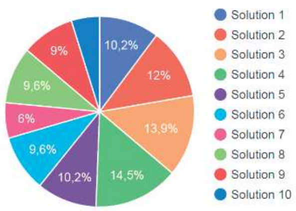
This model could also be used in a distributed way by reducing the number of farmers to one. Obtained non-dominated solutions would not be non-dominated for the whole supply chain but only for the particular farmer.

5.3 GRUS experiment using solutions generated by the centralized model

We used GRUS to rank the 10 generated alternatives. We were five decision makers playing the role of the farmers, including the facilitator as a decision maker. The adopted process was composed by three steps and was the following:

1. Alternatives Generation: The facilitator filled in the system the 10 solutions found thanks to the optimization model.
2. Vote: The five decision makers ranked the 10 solutions according to their own preferences.
3. The system then computes the final ranking for the group using the Borda [23] methodology.

The result is described in the Fig. 3.



1. Solution 4: 24 points
2. Solution 3: 23 points
3. Solution 2: 20 points
4. Solutions 1 and 5: 17 points
5. Solutions 6 and 8: 16 points
6. Solution 9: 15 points
7. Solution 7: 10 points
8. Solution 10: 8 points

Fig. 3. Result of the Group Ranking.

This result is given for the group of five farmers. The five farmers have the same weight (importance) for this experiment. Nevertheless, we also could choose that the importance of each farmer is linked to the number of hectares, only in Multi-Criteria processes.

We can see that on positions 4 and 5 two alternatives are ex aequo: solutions 1 and 5 for rank 4 and solutions 6 and 8 for rank 5. The best solution for the group is the one for which the five farmers have benefits and the three kinds of tomatoes are planted, that is solution number 4. Nevertheless, we can notice that it is not the solution, which generates the best profit on a global point of view.

This experiment shows that the solution obtained by a centralized optimization model that generates the highest profit, that is the solution 1 in the table of the Annex 1, is not necessarily the best one for the group of agents (humans).

6 Conclusion

In this paper, we combined two approaches in order to generate a good solution for a group of human beings. The application domain is the Agriculture. Planning a strategy of production is a difficult task in the agriculture if several constraints, like for example harvesting, ground to plant, choose the best seed, etc. are taken into account.

First of all, we generated 10 solutions thanks to a centralized optimization model. These solutions are then explained to the group of five farmers. We, in a second step, asked to the five farmers to give their own preferences on these 10 solutions. We finally used a Group Decision Support System, called GRUS, to find the final ranking for the group. This final ranking is based on the preferences given by the stakeholders. Nevertheless, the conclusions of this experiment have some limitations based on the fact the decision makers were researchers and not farmers. We still need to do the same experiment with real farmers and obtain their feedback about the process.

We show in this paper how the GDSS GRUS is helpful to generate a group decision which reduces conflicts in a group (Borda voting procedure) and how it supports to find a consensus. These results are interesting but we need to conduct more experiments with a decentralized optimization model and compare the obtained non-dominated solutions with the solutions obtained with the GRUS system.

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ANNEX 1

Table 2. Set of non-dominated optimal solutions for the mathematical programming model

Solution	Profits (€)			Tomato wastes (kg)			Unmet demand	Cherry tomato planting area (ha)			Round tomato planting area (ha)			Pear tomato planting area (ha)		
	SC	Farm		SC	Farm			SC	Farm		SC	Farm		SC	Farm	
1	148.334.625	1	24.758.476	5.316.020	1	998.708	207.317.999	35,9365	1	17,9365	21,6970	1		28,3665	1	2,0635
		2	21.892.373		2				2	18,0000		2			2	
		3	39.408.112		3				3			3	11,6278		3	5,3722
		4	32.890.933		4	4.317.312			4			4	1,5670		4	14,4330
		5	29.384.732		5				5			5	8,5023		5	6,4977
2	148.302.280	1	25.086.408	5.315.998	1	2.115.428	201.749.612	33,6292	1	15,6292	24,0044	1		28,3665	1	4,3708
		2	21.891.207		2				2	18,0000		2			2	
		3	39.407.029		3				3			3	11,6277		3	5,3723
		4	34.825.732		4	3.200.570			4			4	3,3830		4	12,6170
		5	27.091.904		5				5			5	8,9937		5	6,0063
3	148.003.481	1	25.818.920	6.417.520	1	3.958.788	195.841.392	30,4959	1	12,4959	26,0250	1	1,1288	29,4791	1	6,3753
		2	21.889.971		2				2	18,0000		2			2	
		3	39.405.833		3	12			3			3	11,6277		3	5,3723
		4	35.569.237		4	2.458.720			4			4	4,2743		4	11,7257
		5	25.319.522		5				5			5	8,9941		5	6,0059
4	146.849.751	1	26.249.394	11.193.326	1	8.734.549	189.933.239	25,6717	1	7,6717	26,0250	1	1,1293	34,3032	1	11,1989
		2	21.888.734		2				2	18,0000		2			2	
		3	39.404.693		3				3			3	11,6277		3	5,3723
		4	35.568.111		4	2.458.765			4			4	4,2743		4	11,7257
		5	23.738.819		5	12			5			5	8,9937		5	6,0063
5	145.326.260	1	23.810.235	14.017.213	1	11.558.336	184.025.050	21,0899	1	3,0900	26,3350	1	1,4393	38,5751	1	15,4707
		2	21.887.500		2	22			2	17,9999		2			2	
		3	39.403.535		3	10			3			3	11,6277		3	5,3723
		4	35.566.937		4	2.458.822			4			4	4,2743		4	11,7257
		5	24.657.938		5	24			5			5	8,9936		5	6,0064
6	142.518.888	1	23.757.449	11.213.768	1	8.754.980	178.116.854	18,7100	1	0,7100	31,3691	1	6,4735	35,9209	1	12,8165
		2	21.886.261		2				2	18,0000		2			2	
		3	39.402.357		3				3			3	11,6277		3	5,3723
		4	35.565.913		4	2.458.765			4			4	4,2743		4	11,7257
		5	21.906.908		5	23			5			5	8,9936		5	6,0064
7	136.863.913	1	15.839.594	8.410.330	1	4.466.454	172.208.666	14,4576	1		33,0921	1	7,3206	38,4503	1	12,6794
		2	22.373.720		2	1.714.531			2	14,4576		2			2	3,5424
		3	39.401.183		3				3			3	11,6277		3	5,3723
		4	35.435.025		4	2.229.345			4			4	5,1500		4	10,8500
		5	23.814.391		5				5			5	8,9938		5	6,0062
8	146.572.577	1	25.244.207	-	1		204.769.167	37,8087	1	17,6497	26,0250	1		22,1661	1	2,3503
		2	21.891.837		2				2	18,0000		2			2	
		3	39.479.894		3				3			3	11,9768		3	5,0232
		4	34.626.196		4				4	2,1591		4	3,9252		4	9,9157
		5	25.330.443		5				5			5	10,1230		5	4,8770
9	135.083.010	1	22.220.586	-	1		182.724.221	22,8945	1	2,7249	32,5065	1	3,5312	30,5989	1	13,7439
		2	21.887.918		2				2	17,9982		2	0,0016		2	0,0001
		3	39.979.961		3				3			3	7,3755		3	9,6245
		4	34.100.105		4				4	2,1714		4	8,5266		4	5,3020
		5	16.894.441		5				5			5	13,0716		5	1,9284
10	129.129.328	1	15.544.979	25.230.996	1	8.427.387	154.484.078	0,0004	1	0,0003	39,2378	1	8,9728	46,7618	1	11,0269
		2	19.246.325		2	14.995.650			2	0,0001		2	2,8857		2	15,1142
		3	39.397.689		3				3			3	11,6277		3	5,3723
		4	35.193.389		4	1.807.927			4			4	6,7579		4	9,2421
		5	19.746.946		5	32			5			5	8,9937		5	6,0063