Comparison of Software Decision Support Systems for Solving a Multicriteria Optimization Problem

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Abstract: *This article describes in details how multicriteria optimization can be applied to solve a typical business problem for resources planning and manufacturing process optimization in a battery factory. We solve the problem by using an interactive software decision support system WebOptim developed at the Institute of information and communication technologies. The entire problem solving process is described step by step in order to point out the problem specific features as well as to demonstrate the capabilities of the WebOptim software system. For comparison, we have solved the same problem by means of another popular decision support system WWW NIMBUS and both solutions are analyzed and discussed.*

Keywords: *Multicriteria optimization, decision support systems, resource planning.*

1. Introduction

In nowadays business and economy, many problems in complex systems management and control, planning, analysis and monitoring, can be described and solved as multicriteria decision-making problems [1, 16, 17, 19]. These problems on the other hand can be divided into two large classes [2, 3], depending on their formal statement.

First class contains a finite number of explicitly set constraints as functions. These functions define an infinite number of feasible alternatives [4]. These are so called continuous multicriteria optimization problems.

In the second class of problems, there is finite number of alternatives, described in tabular form [5]. These problems are called discrete multicriteria decision making problems or multicriteria analysis problems.

In this paper the focus is on the first class – multicriteria optimization problems. Their specific characteristics are briefly described as follows.

Multicriteria optimization problems are non-formalized or weakly formalized, the solution of which requires active participation of the so-called Decision Maker (DM) [6, 7]. Usually, solutions that are obtained depend very much on the DM's

personal preferences. In multicriteria optimization problems, several criteria (objective functions) are simultaneously optimized into a feasible set of alternatives. Normally a single alternative does not exist that optimizes all the criteria. However, a small subset of alternatives exist, where each improvement in the value of one criterion, leads to deterioration in the value of at least one other criterion. Each solution from this subset is called Pareto-optimal solution [8]. Therefore, when we speak about multicriteria optimization, we speak about finding a good Pareto-optimal solution. What is a “good solution” is a decision, taken by the decision maker.

Two main approaches are used to solve multicriteria optimization problems: scalarizing approach [9] and approximation approach [10]. The scalarizing approach is more popular. In that case, the multicriteria optimization problem is reduced to a single-criteria optimization problem. This approach uses interactive algorithms, where the decision maker has the most important role in the solution finding process. Each interactive algorithm contains two steps - optimization and evaluation, which are repeated in cycle until a final decision is made. In the evaluation step, the decision maker evaluates the current Pareto-optimal solution. If it satisfies his personal preferences the process stops and that current solution becomes a final one. In the other case, the decision maker defines certain preferences concerning changes in criteria values in order to obtain a new Pareto-optimal solution. Based on those preferences in the optimization step a new scalarizing problem is generated and solved, which gives the new consecutive Pareto-optimal solution. As mentioned before - the scalarizing problem is a single-criteria optimization problem, which makes possible using the well-known theory and algorithms for solving single-criteria optimization problems.

Many interactive algorithms are developed, each one having advantages and disadvantages, concerning the type of information that the decision maker provides as a reflection of his personal global and local preferences.

The most important aspect in multicriteria optimization is that the process involves heavy mathematical calculations repeated in multiple iteration cycles. Those calculations are practically impossible to make without the help of so-called decision support systems. They are software systems that provide the decision maker with the tools and ability to solve such problems by implementation of the two steps – optimization and evaluation. These systems are classified in two classes – software systems with general purpose and problem-oriented software systems.

The general-purpose software systems aid the process of finding an optimal solution by different decision makers with different level of experience and knowledge. The systems usually implement one method or several methods from the same group.

Problem-oriented software systems are part of other software systems and serve to aid the solution of one or several types of specific multicriteria optimization problems. Specialized methods and algorithms are also developed in the cases of group and fuzzy multicriteria decision making [20, 21].

Well-known general-purpose software systems, which support the solving of multicriteria optimization problems, are VIG, DIDAS, DINAS, MOLP-16, LBS, SOMMIX, MOIP, WWW-NIMBUS [15], MOLIP, NLPJOB and MOMILP [11,12].

This article demonstrates how to solve a real problem for production planning by using the software decision support system WebOptim [13]. It is an interactive software system for multicriteria optimization, developed at the Institute of information and communication technologies, Bulgarian Academy of Sciences. It implements some of the most well-known algorithms, and one interactive algorithm developed at the same institute [14]. The first author of this article is one of the leading developers of the WebOptim software system. The system is contemporary, user friendly for many users and provides the decision maker with a large variety of instruments to solve multicriteria optimization problems [18].

2. Problem description

The problem under consideration is a benchmark example taken from a book with case studies of typical multicriteria optimization problems [17] and it is adapted for the demonstration purposes of this article. The problem description is as follows.

A Battery fabric is manufacturing three types of batteries for selling on internal and international market:

- Standard capacity battery
- High capacity battery
- Rechargeable battery

The manufacturing process defines certain requirements and dependencies between manpower and machine power for a specific period of time. These dependencies are shown in Table 1.

Table 1. Resources and prices

Parameter	Manpower hours	Machine power hours	Price on internal market	Price on international market
Standard capacity battery	32	19	340	350
High capacity battery	38	21	362	368
Rechargeable battery	39	23	374	378
Available resources	16,000	9,000		
Resource price	4	2.5		

Goal: To optimize the manufacturing process: resources; prices; profit.

Initial Constraints:

Company policy requires selling each battery type on both markets – internal and international. There are also requirements concerning the minimum quantities of each battery type units. They are as follows:

- Minimum 30 units of standard capacity batteries
- Minimum 20 units of high capacity batteries
- Minimum 10 units of rechargeable batteries

Variables:

- ib1 – standard capacity batteries quantity for internal market
- eb1 – standard capacity batteries quantity for international market
- ib2 – high capacity batteries quantity for internal market

- eb2 – high capacity batteries quantity for international market
- ib3 – rechargeable batteries quantity for internal market
- eb3 – rechargeable batteries quantity for international market
- r1 – variable specifying the constraint of manpower resources
- r2 – variable specifying the constraint of machine power resources

Objective functions:

- Maximize the profit F1 (manufacturing price-expenses) –

$$\text{MaxF1} = 164.5 \times \text{ib1} + 174.5 \times \text{eb1} + 157.5 \times \text{ib2} + 163.5 \times \text{eb2} + 160.5 \times \text{ib3} + 164.5 \times \text{eb3},$$

where each coefficient is the difference between the selling price and the manufacturing expenses defined with the following formulae:

$$\text{Coefficient of ib1} = 340 - (4 \times 32 + 2.5 \times 19) = 164.5;$$

$$\text{Coefficient of eb1} = 350 - (4 \times 32 + 2.5 \times 19) = 174.5;$$

$$\text{Coefficient of ib2} = 362 - (4 \times 38 + 2.5 \times 21) = 157.5;$$

$$\text{Coefficient of eb2} = 368 - (4 \times 38 + 2.5 \times 21) = 163.5;$$

$$\text{Coefficient of ib3} = 374 - (4 \times 39 + 2.5 \times 23) = 160.5;$$

$$\text{Coefficient of eb3} = 378 - (4 \times 39 + 2.5 \times 23) = 164.5.$$

Next task is to optimize the using of manpower and machine power resources. This is done through minimizing the difference between the total available resource and the sum of all resource hours necessary for the manufacturing process.

- Minimizing manpower resource F2:

$$\text{MinF2} = 32 \times \text{ib1} + 32 \times \text{eb1} + 38 \times \text{ib2} + 38 \times \text{eb2} + 39 \times \text{ib3} + 39 \times \text{eb3} - 16,000 \times r1.$$

- Minimizing machine power resource F3:

$$\text{MinF3} = 19 \times \text{ib1} + 19 \times \text{eb1} + 21 \times \text{ib2} + 21 \times \text{eb2} + 23 \times \text{ib3} + 23 \times \text{eb3} - 9,000 \times r2.$$

Constraints:

- Manpower resource constraint:

$$32 \times \text{ib1} + 32 \times \text{eb1} + 38 \times \text{ib2} + 38 \times \text{eb2} + 39 \times \text{ib3} + 39 \times \text{eb3} \leq 16,000.$$
- Machine power constraint:

$$19 \times \text{ib1} + 19 \times \text{eb1} + 21 \times \text{ib2} + 21 \times \text{eb2} + 23 \times \text{ib3} + 23 \times \text{eb3} \leq 9,000.$$

After a solid business analysis, managers have settled minimum battery quantity requirements for internal and external market as follows:

$$\text{ib1} \geq 40$$

$$\text{eb1} \geq 40$$

$$\text{ib2} \geq 40$$

$$\text{eb2} \geq 30$$

$$\text{ib3} \geq 20$$

$$\text{eb3} \geq 20$$

3. Solving the problem and making a decision with WebOptim

After entering the problem definition in the WebOptim decision support system (Fig. 1), we obtain auto generated first initial solution (Fig. 2).

WebOptim
Welcome **bobs!** [Log Out]

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MY MCLP PROBLEMS

ID	Title	Created on	Status	Sent to solver on	Syntax	Use solver
Select 24	Batteries production problem	9/20/2017 4:21:20 PM	New		lp	GENS-IM

Edit

New

problem_id

24

Title

Batteries production problem

created_on

9/20/2017 4:21:20 PM

Status

New

Sent to solver on

Description

Optimize battery manufacturing process.

Problem Definition

Max F1 = 164.5 ib1 + 174.5 eb1 + 157.5 ib2 + 163.5 eb2 + 160.5 ib3 + 164.5 eb3
Min F2 = 32 ib1 + 32 eb1 + 38 ib2 + 38 eb2 + 39 ib3 + 39 eb3 - 16000 r1
Min F3 = 19 ib1 + 19 eb1 + 21 ib2 + 21 eb2 + 23 ib3 + 23 eb3 - 9000 r2

32 ib1 + 32 eb1 + 38 ib2 + 38 eb2 + 39 ib3 + 39 eb3 <= 16000
19 ib1 + 19 eb1 + 21 ib2 + 21 eb2 + 23 ib3 + 23 eb3 <= 9000

ib1 >= 40
eb1 >= 40
ib2 >= 40
eb2 >= 30
ib3 >= 20
eb3 >= 20

r1 >= 1
r1 <= 1
r2 >= 1
r2 <= 1

Public problem

☐

Syntax

LP - LPSolve

Solver

GENS-IM

Fig. 1. WebOptim system – problem definition interface

Min/Max	ib1	eb1	ib2	eb2	ib3	eb3	r1	r2	Ideal	Nadir	Step1	Preference
F1 = Max:	164.5	174.5	157.5	163.5	160.5	164.5	0	0	78012.6316	31265	54648	Improve
F2 = Min:	32	32	38	38	39	39	-16000	0	-9220	-647.3696	-4932	Improve
F3 = Min:	19	19	21	21	23	23	0	-9000	-5090	-0.000700000000506407	-2544	Worse

Last Error:

Result

An optimal solution was obtained.

ib1=40.0000 eb1=174.0000 ib2=40.0000 eb2=30.0000 ib3=20.0000 eb3=20.0000 r1=1.0000
r2=1.0000

Scalarized problem: (DALDI/Pure Integer)

Min: Alfa

164.5 ib1 +174.5 eb1 +157.5 ib2 +163.5 eb2 +160.5 ib3 +164.5 eb3 + Alfa >= 54638.8158
32 ib1 +32 eb1 +38 ib2 +38 eb2 +39 ib3 +39 eb3 -16000 r1 - Alfa <= -4933.6848
19 ib1 +19 eb1 +21 ib2 +21 eb2 +23 ib3 +23 eb3 -9000 r2 - Alfa <= -2545.00035
32 ib1 +32 eb1 +38 ib2 +38 eb2 +39 ib3 +39 eb3 <= 16000

Fig. 2. WebOptim system – initial solution and preferences set for the next step

Result values related to batteries quantity are given in Table 2 and objective function values are in Table 3.

Table 2. Battery quantity – initial values

Market	Standard capacity	High capacity	Rechargeable
Internal	40	40	20
International	174	30	20

Table 3. Objective function initial values

F1	F2	F3
54,648	-4,932	-2,544

The first conclusion is that here we have optimized the resources (F2 and F3), but the profit (F1) seems to be unsatisfying. From mathematical viewpoint, this solution is Pareto-optimal, but in business terms, we could ask for more. Here comes the decision maker's active role. It is obvious that the highest profit comes after selling on international market. In our case, the battery quantities for international market are too low. In order to improve the value of objective function F1 (profit), we have to choose which other criterion to worsen and how to worsen. The manager's decision is to worsen the objective function related to machine power resources (F3), because they are cheaper. On the other hand, if we just set preferences to worsen this value, it might go right to its bottom point and we do not want that.

However, as a beginning, we would like to do exactly that – worsen the use of resources, just to see what values will come when maximizing the profit. Later we will do some more changes.

After choosing free improvement of F1 and free worsening of F2 and F3, we obtain the next values shown in Fig. 3, Table 4 and Table 5.

Min/Max	ib1	eb1	ib2	eb2	ib3	eb3	r1	r2	Ideal	Nadir	Step1	Preference	Step2	Preference
F1 = Max:	164.5	174.5	157.5	163.5	160.5	164.5	0	0	78012.6316	31265	54648	Improve	77856.5	undefined
F2 = Min:	32	32	38	38	39	39	-16000	0	-9220	-647.3696	-4932	undefined	-676	undefined
F3 = Min:	19	19	21	21	23	23	0	-9000	-5090	-0.0007000000000506407	-2544	undefined	-17	undefined

Last Error:

Result

An optimal solution was obtained.
 ib1=40.0000 eb1=307.0000 ib2=40.0000 eb2=30.0000 ib3=20.0000 eb3=20.0000 r1=1.0000
 r2=1.0000
 Scalarized problem: (DALDI/Pure Integer)
 Min: Beta
 164.5 ib1 +174.5 eb1 +157.5 ib2 +163.5 eb2 +160.5 ib3 +164.5 eb3 >= 54648
 164.5 ib1 +174.5 eb1 +157.5 ib2 +163.5 eb2 +160.5 ib3 +164.5 eb3 +54648 Beta >= 54648
 32 ib1 +32 eb1 +38 ib2 +38 eb2 +39 ib3 +39 eb3 <= 16000
 19 ib1 +19 eb1 +21 ib2 +21 eb2 +23 ib3 +23 eb3 <= 9000
 ib1 >= 40

Fig. 3. WebOptim system – second step results

Table 4. Battery quantity – Step 2 values

Market	Standard capacity	High capacity	Rechargeable
Internal	40	40	20
International	307	30	20

Table 5. Objective function – Step 2 values

F1	F2	F3
77,856.5	-676	-17

As expected – we have maximized the quantity of standard capacity batteries for export, because they have the highest profit rate. Again as expected – the difference in resources usage functions values is too big compared to the initial solution (Fig. 4). Now we have to optimize that too. Manpower resources (F2) are expensive and we would like to keep them at better value. From the current point, we choose to improve that value with aspiration level of at least -6,000.

Machine power resources (F3) are cheaper and we choose to set their value to be improved to aspiration level of at least –1,500. And in order to control the worsening of F1 function, we choose to worsen it to aspiration level of no more than 40,000 (Fig. 4).

	ib1	eb1	ib2	eb2	ib3	eb3	r1	r2	Ideal	Nadir	Step1	Preference	Step2	Preference	Step3	Preference
z	164.5	174.5	157.5	163.5	160.5	164.5	0	0	78012.6316	31265	54648	Improve	77856.5	Worse to 40,000.0000	40164.5	undefined
z	32	32	38	38	39	39	-16000	0	-9220	-647.3696	-4932	undefined	-676	Improve to -6,000.0000	-7588	undefined
z	19	19	21	21	23	23	0	-9000	-5090	-0.000700000000506407	-2544	undefined	-17	Improve to -1,500.0000	-4121	undefined

Last Error:

Result:

An optimal solution was obtained.

ib1=40.0000 eb1=91.0000 ib2=40.0000 eb2=30.0000 ib3=20.0000 eb3=20.0000 r1=1.0000

r2=1.0000

Scalarized problem: (DALDI/Pure Integer)

Min: Alfa

164.5 ib1 +174.5 eb1 +157.5 ib2 +163.5 eb2 +160.5 ib3 +164.5 eb3 >= 40000

32 ib1 +32 eb1 +38 ib2 +38 eb2 +39 ib3 +39 eb3 -16000 r1 <= -676

32 ib1 +32 eb1 +38 ib2 +38 eb2 +39 ib3 +39 eb3 -16000 r1 <= -676 Alfa <= -6000

19 ib1 +19 eb1 +21 ib2 +21 eb2 +23 ib3 +23 eb3 -9000 r2 <= -17

19 ib1 +19 eb1 +21 ib2 +21 eb2 +23 ib3 +23 eb3 -9000 r2 -17 Alfa <= -1500

Fig. 4. WebOptim system – third step results

After solving the new problem, we obtain the values given in Tables 6 and 7.

Table 6. Battery quantity – Step 3 values

Market	Standard capacity	High capacity	Rechargeable
Internal	40	40	20
International	91	30	20

Table 7. Objective function – Step 2 values

F1	F2	F3
40,164.5	-7,588	-4,121

At that point, we are satisfied with the value of the objective function that is related to manpower resources and we would like to keep it as it is. The profit can be improved more on the account of the cheaper machine resources. In order to improve F1, we choose to worsen F2 to a level of –5,000 and worsen F3 to a level of –1,500. After solving, we obtain the values given in Tables 8 and 9.

Table 8. Battery quantity – final step values

Market	Standard capacity	High capacity	Rechargeable
Internal	40	40	20
International	171	30	20

Table 9. Objective function – final step values

F1	F2	F3
54,124.5	-5,028	-2,601

Our decision is to keep those values as a final solution, where we guaranteed the maximum profit and optimal resources usage.

4. Solving the problem with Nimbus

To compare the problem solving process, obtained results and overall user experience, we choose to solve the same task with another popular decision support system that solves similar problems – WWW NIMBUS (www.nimbus.it.jyu.fi) [15].

The input interface of Nimbus is presented on Fig. 5.

You must specify at least some values for variable autofill. Please check variable 1.

Input Problem

Fill in all the fields, please. Note that the function and the variable names are used when displaying results, and the variable names x1, x2, x3, etc. must be used when defining the problem.

Objective functions to be optimized

name	expression	Lowest Value	Highest Value
Max ▾ f1	$164.5 \cdot b1 + 174.5 \cdot eb1 + 167.5 \cdot b2 + 163.5 \cdot eb2 + 160.5 \cdot b3 + 164.5 \cdot eb3$	31265	78012.631
Min ▾ f2	$32 \cdot b1 + 32 \cdot eb1 + 38 \cdot b2 + 38 \cdot eb2 + 39 \cdot b3 + 39 \cdot eb3 - 16000 \cdot r1$	-9220	-647.3696
Min ▾ f3	$19 \cdot b1 + 19 \cdot eb1 + 21 \cdot b2 + 21 \cdot eb2 + 23 \cdot b3 + 23 \cdot eb3 - 9000 \cdot r2$	-0.0007	5090

Use [Standard functions available](#)

Variables

☐ Use autofill

	lower bound	starting point	upper bound	Integer values
x1	40	40	100000	☒
x2	40	40	100000	☒
x3	40	40	100000	☒
x4	30	30	100000	☒
x5	20	20	100000	☒
x6	20	20	100000	☒
x7	1	1	1	☒
x8	1	1	1	☒

Linear Constraints

	Ax								b
No1 : 32	*x1 + 32	*x2 + 38	*x3 + 38	*x4 + 39	*x5 + 39	*x6 + 1	*x7 + 1	*x8 + 1	16000
No2 : 19	*x1 + 19	*x2 + 21	*x3 + 21	*x4 + 23	*x5 + 23	*x6 + 1	*x7 + 1	*x8 + 1	9000

Next optimization: Global 1 + Local (PB) ▾

Fig. 5. Nimbus system – problem definition interface

The initial solution that is generated from Nimbus has exactly the same values as this from WebOptim. After two more iterations with similar preferences, the obtained results are given in Table 10.

Table 10. Comparison between obtained solutions from WebOptim and WWWNimbus by steps

Step	System	ib1	eb1	ib2	eb2	ib3	eb3	F1	F2	F3
1	WebOptim	40	174	40	30	20	20	54,648	-4,932	-2,544
1	Nimbus	40	174	40	30	20	20	54,648.0	-4,932	-2,544
2	WebOptim	40	91	40	30	20	20	40,164.5	-7,588	-4,121
2	Nimbus	40	40	40	30	20	20	31,265	-9,220	-5,090
3	WebOptim	40	171	40	30	20	20	54,124.5	-5,028	-2,601
3	Nimbus	40	174	40	30	20	20	54,648.0	-4,932	-2,544

It is seen from the results in Table 10, that at the first step of optimization both software systems WebOptim and Nimbus give exactly the same Pareto-optimal solution. However, applying the specific decision maker's preferences described in the previous section, we obtain different alternatives in the next two steps.

In particular, at Step 2 the solution obtained by WebOptim is characterized by a substantially better value of the obtained profit (objective function F1) and relatively worse values of the manpower and machine power resources (objective functions F2 and F3) as compared to the respective values in the solution of the Nimbus system. At this step it can be concluded that both solutions are acceptable as they satisfy all constraints of the optimization problem and the decision maker's preferences. Thus, the decision maker can choose one of them depending on some additional economic preferences and/or production process specifics.

At Step 3 it is seen that the solution obtained by Nimbus actually repeats the initial Pareto-optimal solution. At the same time the WebOptim system produces a solution which is characterized by a slightly worse value of the objective function F1 and better values of objective function F1 and F2. Thus at this step the software system WebOptim provides another more alternative which gives the decision maker more possibilities to find the most appropriate final decision.

5. Conclusion

In this work we presented and analysed in details the solving process of a multicriteria optimization problem and the corresponding decision making for an efficient resources planning and production process optimization in a battery manufacturing company. The entire solving process involves three main components: mathematical model of the production process and business requirements, specialized software implementing algorithms for multicriteria optimization and the active participation of the decision maker. We have used an interactive decision support system WebOptim in order to find a Pareto optimal solution of the problem together with several alternative solutions corresponding to different preferences of the decision maker. For comparison, the same task is solved with another software system WWW Nimbus supporting the decision making in similar problems. An analysis of both solutions indicates that WebOptim is advantageous in providing more alternatives for making the most appropriate final decision. In a future perspective, it would be useful to develop and implement new exact and heuristic algorithms for solving wider range of complex optimization problems. Finally, as a general conclusion it should be noted that real life decision making problems are difficult to solve and only the combination of exact mathematical model, efficient software tools and active participation of the decision maker is a guarantee for finding a scientifically justified solution.

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