MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
SUMY STATE UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE

MASTER THESIS

On the topic:

Computer System For Operational Control Of The Optimal Flow Of The Technological Process

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DEPARTMENT OF COMPUTER SCIENCES

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Task of Master Work

Fourth-year student, group IN.M-05AH specialty "Informatics" Kama O. I.

On the topic: "Computer System For Operational Control Of The Optimal Flow Of The Technological Process"

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№_________ of __________ 2021

Content of Explanatory Note: 1) An analytical review of the literature; 2) Statement of the problem; 3) The choice of methods for solving the problem; 4) Develop models 5) Conclusions.

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Supervisor of Bachelor work _______________ Avramenko V. V.

Task adopted to be implemented by _____________ Kama O.

ABSTRACT

Note: 40 pages, 7 figures, 4 tables, 3 graphs, 14 sources literature, 1 app.

Object of study – Optimal flow of the technological process.

Purpose – To adequately control the optimal flow of the technological process.

Research method – disproportionality function.

Results – A computer system which controls the optimal flow of the technological process was created showing places of distortion.

KEYWORDS – Optimal, flow, optimal flow, operational, control, operational control, technological, process, technological process, disproportionality, n-order derivative disproportionality function.

CONTENTS

INTRODUCTION

Optimal flow is an essential part of life which makes it a very important aspect of life. Due to a rising demand in the need for efficiency, optimization of technological processes has seen a great surge in the recent past. As the world's population increases, resources become scarcer thereby making waste something to be frowned upon. Simply put, waste is not profitable and will have a negative impact on any individual, company or organization that functions with a policy that accommodates wastage. This cuts across all spheres of life ranging from sports, food production, production of raw materials and basically anything that is produced.

Due to the desire to be the best, produce the best results or simply make more profit, companies and individuals are beginning to use methods to help to achieve optimal flow in their daily activities. For example, it is not wise to use 20 big trees to make one small table when using one or two trees would have been sufficient for the task; It is also not wise to make two or three people do the task that one person can do effectively without reducing the organization's output. The scenarios stated earlier just show that making the best of what you have has become an absolute necessity in life. Sometimes this waste is not visible to the naked eye that's why we need special methods to make sure we get the best results. This is where optimal flow comes in to give you the best result.

Depending on the production conditions, unit costs may randomly deviate from the optimal values especially when there is unsatisfactory operation of the automatic system and our job here will be to create an algorithm and a computer program to detect the appearance of deviation of the specific consumption of raw materials from the optimal values.

1. LITERATURE REVIEW

Looking at what is in the world today, you would say that there has been good progress when it comes to optimal flow in different areas and spheres. Even though there has been progress, we shouldn’t settle for what is available, rather, we should look towards advancing and making life better by improving productivity. In this section, we will take a glimpse at the technological state of optimal flow of technological processes at the moment before we go to what we have to offer in order to make the world a better place.

1.1 OPERATIONAL CONTROL

One of the best ways to get the proper meaning of a word, though easy, is by simply looking it up. Getting an understanding of the major words we have will help us better understand the meaning and scope of this project and the direction we are going in.

Here goes the first question, which is: What is operational control? Breaking down the complex word is the first step into understanding operational control. Operational as the word implies comes from the word operation which means functioning. That means when you say the car is operational, it means the car is functioning the way it is supposed to function. Control on the other hand simply means the direction of the cause of events. Another word you can use for control is influence [1].

Looking at operational control as a whole tells you that operational control is simply control or influence over the operation of a thing or process. This means you are in charge of how something goes.

Operational control also can be seen as a system with is created to establish the smooth sailing of everyday affairs and to make sure that these affairs are consistent with the already laid down goals and plans of an institution. In a case where the performance is not up to the desired goal, correction is taken and things are adjusted. The image below shows the difference between planning and controlling [2].

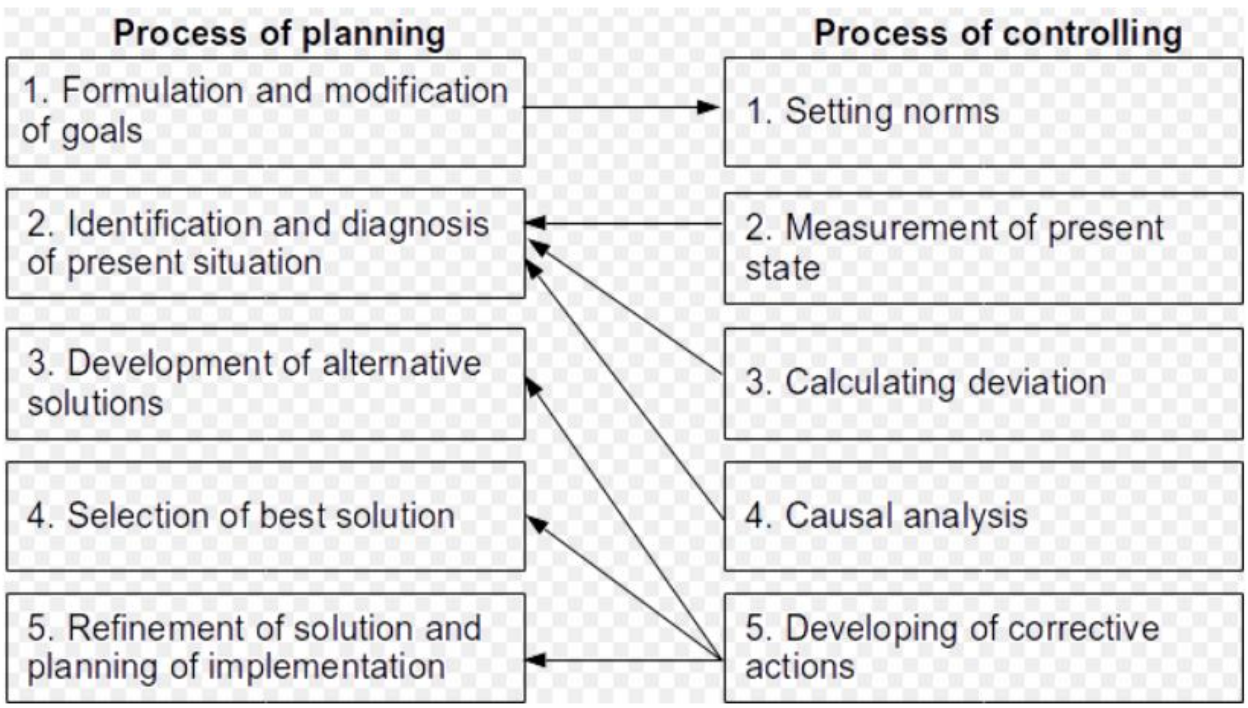


Fig 1.1.1 – Diagram above show process of planning and controlling

1.2 OPTIMAL FLOW

In lay man’s terms, you can simply say that optimal flow is the flow of operation in the best way possible and the truth is you won’t be far from the truth. Basically, that is the truth but we will go a little deeper into the definition and areas that have to do with this sphere which is optimal flow in manufacturing. When it comes to manufacturing, optimal flow is the steady flow of materials as determined in the organization's system [3].

ADVANTAGES OF OPTIMAL FLOW OF MATERIALS

There are many benefits of optimal flow of materials and below are a few advantages and benefits when optimal flow has been achieved.

1. There is a drastic improvement in the performance of the system which equates to positive results which equates to meeting more needs.
2. There is a reduction in the energy that is spent which means more attention can be given to other areas of need.
3. Maximizing production rate is one of the greatest desires of every industry and with the right implementation, this can be achieved.
4. Optimal flow of materials reduces the cost of operation and also the cost of maintenance which reduces waste [3].

DATA SILOS

One of the biggest challenges faced when it comes to optimization of the flow of materials in industries is siloed data. What is siloed data one may ask? This is data which is not centralized in an organization but made available to only one group or team [4].

DRAWBACKS OF DATA SILOS

Data silos exist for different reasons and some may even root for it or go out of their way to insist on its importance which can be true and very legitimate for some cases but it's drawbacks in a manufacturing company can be humongous. This is because without proper circulation of data, there could be a risk of reduced performance [4]. Below is a list of some of the potential drawbacks one might face when using siloed data.

1. There is a difficulty is quickly detecting issues and resolving them as such.
2. Because data is in different silos, you can have issues where teams or groups in an organization don't seem to work together.
3. Employees can spend valuable time looking for the right piece of information which wouldn't have been a problem in a centralized system.
4. There can be a risk of inaccurate data being used.
5. Poor decisions are difficult to totally eradicate because there is always the risk of taking the wrong step due to limited information. [4][5]

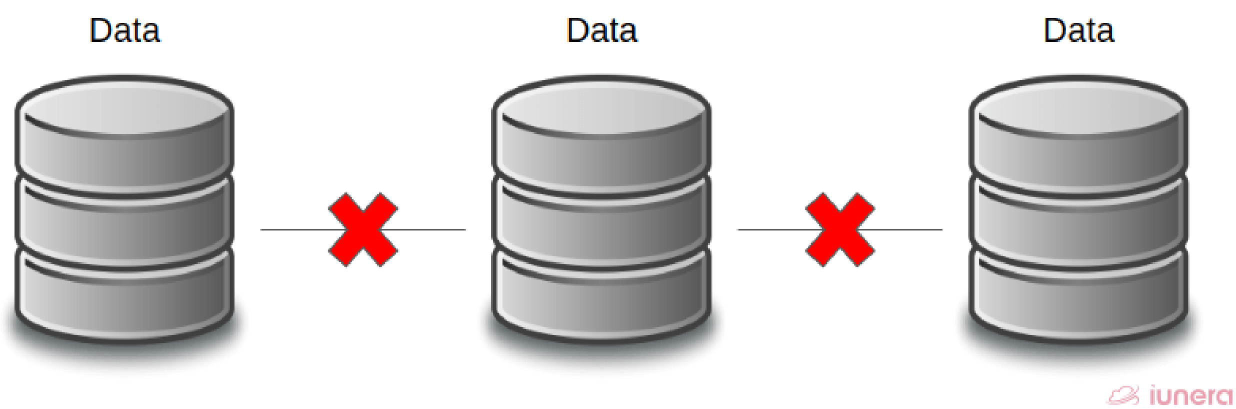


Fig 1.2.1 - Pictorial representation of siloed data [6]

BLEND OPTIMIZATION

Finding the perfect balance between quality and cost is one of the biggest tasks of any organization and this is where blend optimization comes in. The best quality is what every consumer wants which makes companies want to go out of their way to get the very best for the general public but companies also have to look at the cost of the raw materials involved in making these products. Blend optimization uses linear programming as a mathematical model in order to derive the best result [7].

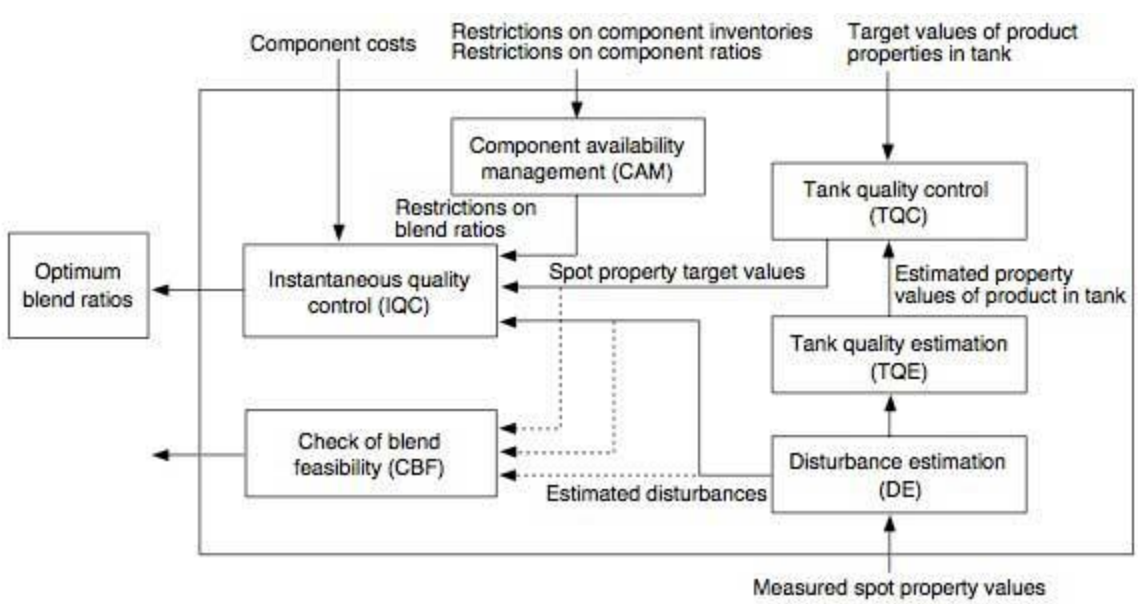
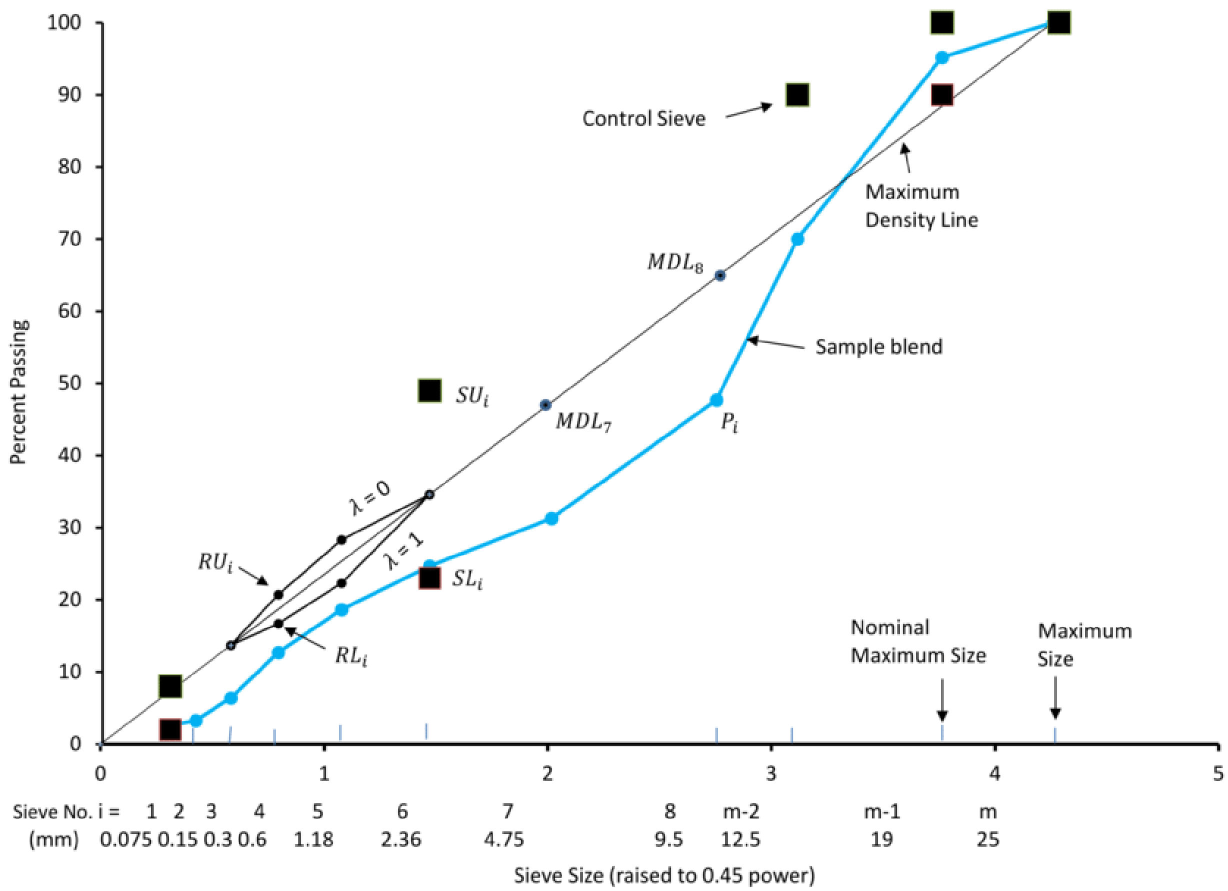


Fig 1.2.2 – A diagram of the functional process of Blend optimization [8]



Graph 1.2.1 – Graph of blend gradation [9]

2. OPERATIONAL CONTROL FOR OPTIMAL FLOW

What we would look at next is operational control for optimal flow. Having gone through the definitions of the foundational words which are operational control and optimal flow, we would go deeper to have a better grasp of this project. Operational control for optimal flow is the influence and guidance one has over the optimal flow of events or raw materials as the case may be. In this case, we are looking at technological processes and how to have the best functioning technological process in an industry [10].

For example, let’s say you are making orange juice and you have your raw materials to make very good orange juice, you need to find the right balance to get the best result. Yes, there are raw materials which are the oranges, syrups, sugar, water etc., and also the individuals who are in charge of them. Our job is to make sure there is no deviation of the consumption of raw materials from the optimal values.

2.1 LINEAR PROGRAMMING FOR BLENDING

The linear programming model is one of the most popular methods that is seen and used especially in the petroleum and oil industry. Linear programming works by finding thee maximum and minimum of an objective function which are based on a set of constraints. This can be translated to a real-life scenario whereby raw materials are represented with variables then put into a mathematical formula. This data is then used to figure out the perfect blend of raw materials and how to have optimal values in a world where demand grow with the explosion of the world population [11].

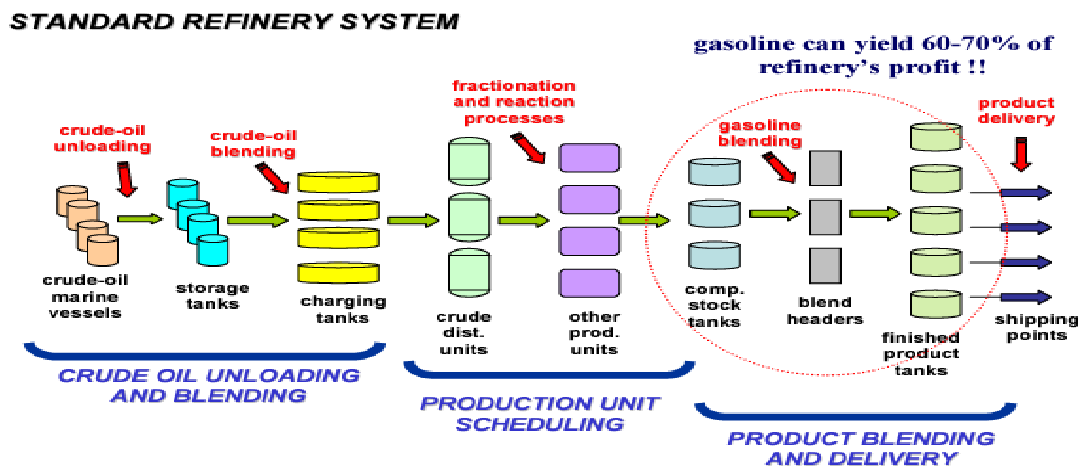


Fig 2.1.1 – Image showing the operation of a refinery system [12]

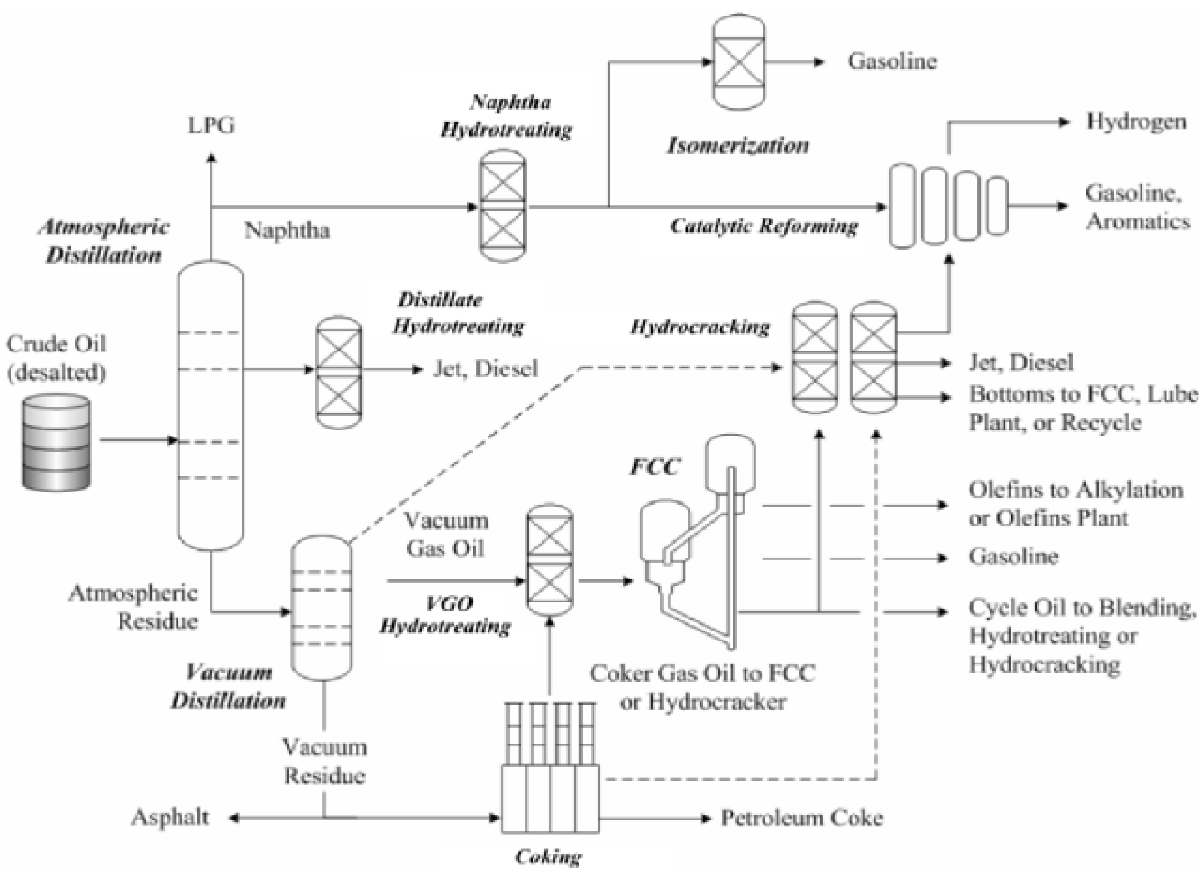


Fig 2.1.2 – Visualization of a high-yielding refinery [13]

2.2 DISPROPORTIONALITY FUNCTION

In determining new characteristics of numerical equations or functions, we will look at the case of almost stationary objects which have unchanged characteristics at a particular time with the mathematical equation below:

$$y = k(t)x \qquad (1)$$

x, y – input and output parameters respectively;

t – time

k(t) – performs a gradual change in respect to x(t).

These objects could range from sensors, converters, tracking systems and much more.

The unchanged character in a general overview becomes:

$$y = k(x,t)x + b(t), \qquad (2)$$

Where $b(t) \neq 0.$

Comparing the values of (1) and (2) will be ideal but k(t) in (1) changes continuously because we are dealing with almost stationary objects which makes it much more difficult.

In a case where x from (2) is not proportional to y, we do not compare the values because k(t) is unknown [14].

2.3 STATEMENT OF PROBLEM

Let X be a set of real numbers and T be a set of real ordered numbers. The set Y which is a set of real numerical functions be defined as;

$$y = f(x,t), \qquad (3)$$

Where $x \in X, t \in T.$

For given values $x \in X$ and $t \in T$, the functional on the set Y must be zero if x and y=f(x, t) is proportional [15].

2.4 PROBLEM SOLUTION

Firstly, solving for one variable is how to begin;

Having;

$$y = f(x), \; x \in X \; .$$

Derivative of y = f(x) is $\frac{dy}{dx}$

Limit of ratio $\frac{\Delta y}{\Delta x}$ for $\Delta x \to 0.$

Hence;

$$\frac{y}{x} = \frac{dy}{dx}, \qquad (4)$$

Is used for any given $x \in X$, and based on the relationship between x and y which is proportional, y = cx, with c = const, then (4) is satisfied. [14]

Case 1

The disproportionality in respect to the 1st order derivative in the case of the function y = f(x) is the difference between $\frac{y}{x}$ and $\frac{dy}{dx}$.

Therfore,

$$@d_x^{(1)}y = \frac{y}{x} - \frac{dy}{dx} \qquad (5)$$

@ - disproportionality determining operation

d – derivative

Logic

y = cx, c = const, is the only case where condition (4) is performed

Looking at the first order derivative where, we see that from y = f(x, t), where $x \in X, t \in T$;

$$@d_x^{(1)}y_t = \frac{f(x,t)}{x} - f_x'(x,t), \qquad (6) \quad [14]$$

2.5 N-ORDER DERIVATIVE DISPROPORTIONALITY

The n-order derivative must be equal to zero so that;

$$y = cx^n \qquad (8)$$

For (8), we have;

$$\frac{y}{x^n} = \frac{1}{n!}\frac{d^n y}{dx^n} \qquad (9)$$

Case 2

The derivative of y = f(x) with respect to x;

$$@d_x^{(n)}y = \frac{y}{x^n} - \frac{1}{n!}\frac{d^n x}{dx^n}, \qquad (10)$$

The derivative of y = f(x, t) with respect to x;

$$@d_x^{(n)}y_t = \frac{f(x,t)}{x^n} - \frac{1}{n!}\frac{\partial^n x}{\partial x^n}, \qquad (11)$$

n – an integer greater than 0 (zero).

When the origin is transferred for fixed t to the point M(x0, y0, t), (11) changes to;

$$@d_{x-x_0}^{(n)}(y-y_0) = \frac{f(x,t)-y_0}{(x-x_0)^n} - \frac{1}{n!}\frac{\partial^n f(x,t)}{\partial x^n} \qquad (12)$$

In the case $y = f(x_1, x_2, x_3, \ldots, x_p, t)$;

$$@\partial_{x_i}^{(n)}y_t = \frac{y}{x_i^n} - \frac{1}{n!}\frac{\partial^n y}{\partial x_i^n} \qquad [14]$$

2.6 DERIVATIVE DISPROPORTIONALITY WHEN A FUNCTION IS SPECIFIED IN FORM OF PARAMETERS

Let $x = \varphi(t), \quad y = \psi(t),$

Where,

$t \in [T_1, T_2]$ and inverse function $t = \Phi(x)$ exists.

For $y = \Psi[\Phi(x)]$, applying $\frac{d^n y}{dx^n}$ in the case of parametric dependence of y on x.

For n = 1;

$$@d_x^{(1)}y = @_{\phi(t)}^{(1)}\psi(t) = \frac{y}{x} - \frac{y_t'}{x_t'} = \frac{\psi(t)}{\phi(t)} - \frac{\psi_t'\ (t)}{\phi_t'(t)} \qquad (15)$$

Is equal to zero for $\psi(t) = c\phi(t)$, where c = const [14].

2.7 VALUE DISPROPORTIONALITY FUNCTIONS

Case 3

The n-order value of disproportionality with respect to x^n equates (10) multiplied by x^n.

It is showcased as $@v_x^{(n)}y$

$$@v_x^{(n)}y = y - \frac{x^n}{n!}\frac{d^n y}{dx^n} \qquad (16)\ [14]$$

For n = 1,

$$@v_x^{(1)}y = y - x\frac{dy}{dx} \qquad (17)$$

For $y = f(x,t)$, $x \in X$, $t \in T$ the value of disproportionality from x^n.

n – integer greater than zero (0), which is solved for fixed t;

$$@v_x^{(n)}y_t = y_t - \frac{x^n}{n!}\frac{d^n y_t}{dx^n} \qquad (18)$$

If they are in parametric form according to (15), then

$$@v_x^{(1)}y = @v_{\phi(t)}^{(1)}\psi(t) = \psi(t) - \phi_t(t)\frac{\psi_t'(t)}{\phi_t'(t)} \qquad (19)\ [15]$$

2.8 PROPERTIES OF DISPROPORTIONALITIES FUNCTIONS

Case

Given the function y = f(x, t),

$x \in X, t \in T$. Let $@d_x^{(n)}y_t \neq 0$ but $@(n)@d_x^{(1)}y_t = 0$. Proving that y = f(x, t) takes the form;

$$y = k_n(t)x^n + k_{n-1}(t)x^{n-1} + \ldots + k_1(t)x, \qquad (20)$$

Logic

We need to prove that the disproportionality with respect to the n-order isn't zero (0).

From (11)

$$@d_x^{(n)}y_t = \frac{1}{x^n}[k_{n-1}(t)x^{n-1} + k_{n-2}(t)x^{n-2} .. + k_1(t)x]. \qquad (21)$$

From this, we know that one of $k_{n-1}(t), k_{n-2}, \ldots, k_1(t)$ doesn't equate to zero.

Looking at the sequence where $@(n)@d_x^{(1)}y_t$ of n first-order (6) for (20).

For easy comprehension, Z signifies each disproportionality in the sequence.

$$Z_1 = @d_x^{(1)}y_t = -[(n-1)k_n(t)x^{n-1} + \\ (n-2)k_{n-1}(t)x^{n-2} + \ldots + 2k_3(t)x^2 + k_2(t)x]$$

$$Z_2 = @d_x^{(1)}Z_1 = [(n-1)(n-2)k_n(t)x^{n-2} + \\ +(n-2)(n-3)k_{n-1}(t)x^{n-3} + .. + 6k_4(t)x^2 + 2k_3(t)x] \quad \ldots$$

$$Z_i = @d_x^{(1)} Z_{i-1} = (-1)^i \sum_{j=i}^{n} k_j(t) x^{j-i} \prod_{m=1}^{i} (j-m)$$

$$\ldots$$

$$Z_{n-1} = @d_x^{(1)} Z_{n-1} = (-1)^{n-1} (n-1)! k_n(t) x$$

$$Z_n = @d_x^{(1)} Z_{n-1} = 0$$

This was the expected result needed [14][15][16].

3. FORMULATION OF THE PROBLEM

Two types of products are made from two types of raw materials. It is known how much raw materials are consumed per unit of time and the optimal specific costs of raw materials for the production of each type of product.

Depending on the production conditions, unit costs may randomly deviate from the optimal values. In particular, the conditions for production deteriorate if, due to the unsatisfactory operation of the automatic control system, the supply of one or both types of raw materials exceed the optimal values, or with a constant supply of raw materials, the uncontrolled characteristics of the raw materials have changed.

It is necessary to develop an algorithm and a computer program to detect at the current time the fact of the appearance of a deviation of the specific consumption of raw materials from the optimal values.

3.1 MATHEMATICAL FORMULATION OF THE PROBLEM

Let's denote:

x - the amount of the first raw material consumed per unit of time at the current time;

y - the amount of the second raw material consumed per unit of time at the current time;

A - the amount of products of the first type at the current time;

B - the amount of products of the second type at the current time;

a_{11}- the specific consumption of the first raw material for the production of a unit of the first type of product;

a_{12} - the specific consumption of the first raw material for the production of a unit of the second type of product;

a_{21} - the specific consumption of the second raw material for the production of a unit of the first type of product;

a_{22} - the specific consumption of the second raw material for the production of a unit of the second type of product;

Thus, under optimal conditions, the production of products can be described as follows:

$a_{11}x + a_{12}y = A;$ (1)

$a_{21}x + a_{22}y = B;$ (2)

In the time interval when, due to the poor operation of the automatic control system, the specific consumption of raw materials depends on the amount of raw materials, the process is described by the equations:

$a_{11}(x,y)x + a_{12}(x,y)y = A;$ (3)

$a_{21}(x,y)x + a_{22}(x,y)y = A;$ (4)

Obviously, solving the problem is reduced to detecting the fact of violation of the affine relationship between the amount of raw materials and the amount of products produced.

It is known [] that for affine-related parameters there is a proportional relationship between the areas of the figures in the area of defining the parameters. The proportionality coefficient k has the form:

$k=a_{11}a_{22}-a_{12}a_{21}$ (5)

Thus, the task is reduced to detecting a violation of the proportional relationship between the areas of the figures. The first of them is obtained as a result of changes in time of x and y, and the second is based on the corresponding values of A and B.

3.2 CHOICE OF METHOD FOR SOLVING THE PROBLEM

To solve the problem, it is necessary to control the proportional relationship between the areas of the figures at the current time. From the literature review it follows that for this purpose it is advisable to use the disproportion functions [ ].

Taking into account the discrete nature of the change in time, the integral disproportionality of the first order [ ] is chosen.

3.3 PROCESS OF SOLVING THE PROBLEM

In the production process, resources x and y are consumed at a constant rate.

Here:

x = ih,

where i = 0, 1, 2, … N - discrete time;

N is the duration of the process;

h is the amount of change of resource x.

According to the condition, the production process requires a certain amount of resource y per unit of resource x, which is described by the expression

$y = Cx^b. = C (ih)^b$,

where C and b are given constants.

It is supposed to calculate the areas of triangles by three points. Specifically, the area of each triangle is determined by the current and two previous points.

Let's denote the current value of the resource x through x_i. Previous values are x_{i-1} and

x_{i-2}. Accordingly, for the resource y we denote by y_i, y_{i-1} and y_{i-2}.

The area s_i of a triangle defined by x and y is described by the expression:

$$s_i = \frac{1}{2}\begin{vmatrix} x_{i-2} & y_{i-2} & 1 \\ x_{i-1} & y_{i-1} & 1 \\ x_i & y_i & 1 \end{vmatrix} = 0{,}5((x_{i-2} - x_{i-1})(y_{i-2} + y_{i-1}) + (x_{i-1} - x_i)(y_{i-1} + y_1) +$$

$$+ (x_i - x_{i-2})(y_i + y_{i-2})); \qquad (6)$$

The area S_i* of a triangle defined by A and B is described by the expression:

$S_i^* = \frac{1}{2} \begin{vmatrix} A_{i-2} & B_{i-2} & 1 \\ A_{i-1} & B_{i-1} & 1 \\ A_i & B_i & 1 \end{vmatrix}$=0,5(($A_{i-2} - A_{i-1}$)($B_{i-2} + B_{i-1}$)+($A_{i-1} - A_i$)($B_{i-1} +$ B_1)+

+(A_i - A_{i-2})($B_i + B_{i-2}$)); (7)

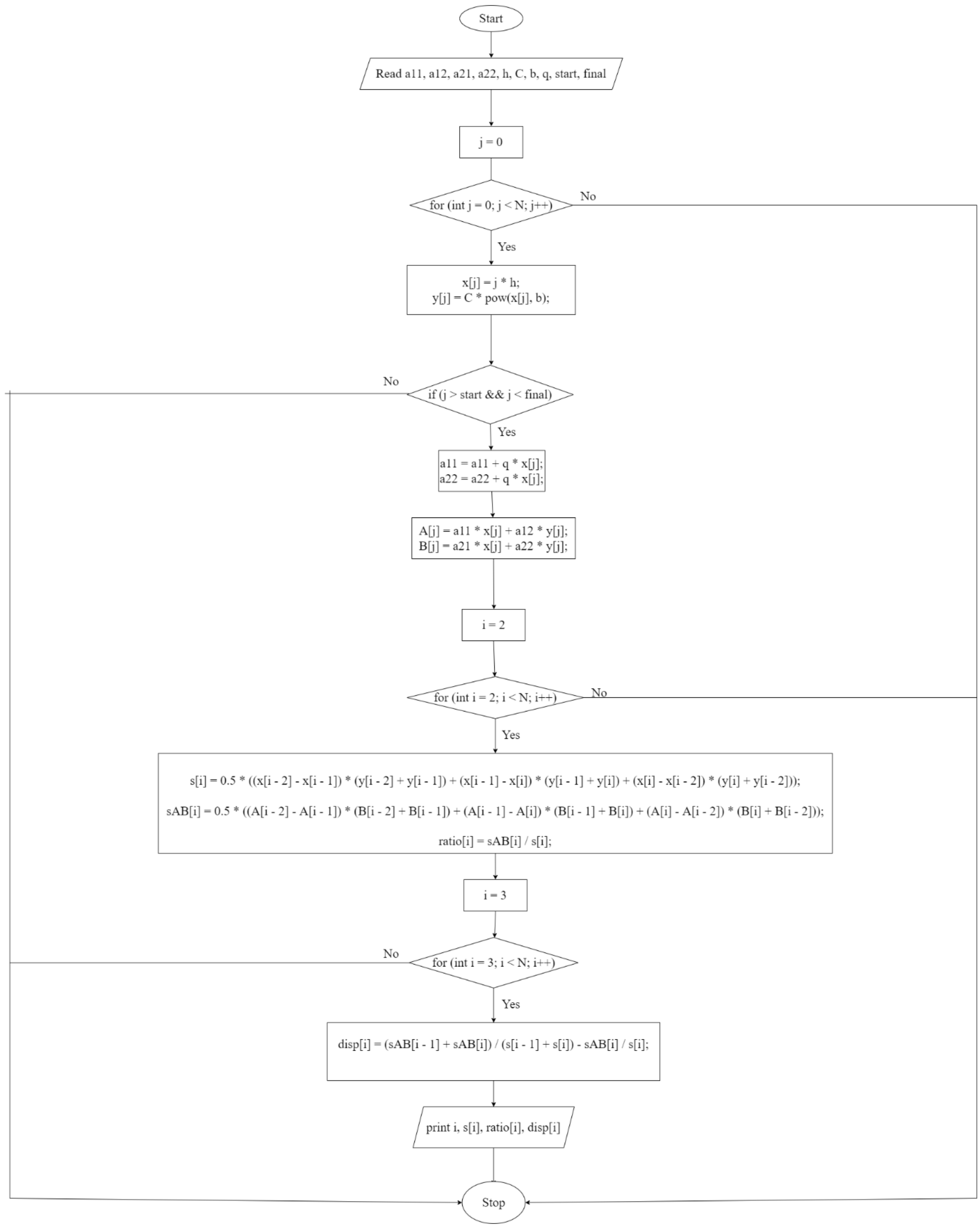
It is necessary to calculate the integral disproportionality of the first order $@I_{s_i}^{(1)} S_i^*$ of area S_i* by s_i.

$I_i = @I_{s_i}^{(1)} S_i^* = \frac{S_{i-1}^* + S_i^*}{s_{i-1} + s_i} - \frac{S_i^*}{s_i}$ (8)

With optimal process, when the process is described by the system of equations (1) and (2), disproportionality (8) will be equal to zero.

On the time interval when the process deviated from the optimal one and is described by equations (3) and (4), the affine connection between the parameters x, y at the input of the system and A, B at its output is broken. As a consequence, the proportional relationship between the areas S_i* and s_i disappears. This will lead to the fact that disproportion (8) will not be equal to zero in this interval. On this basis, at the current moment of time, the fact of the appearance of a deviation of the specific consumption of raw materials from the optimal values is detected and thus the task is being solved.

3.4 ALGORITHM FOR SOLVING THE PROBLEM



The table below shows the use of identifiers used in the algorithm

Table 3.4.1

VARIABLES	IDENTIFIERS	EXPLANATION
N	N	Duration of the process
i	J, i	Discrete time i = 0, 1, 2, …N
X, y	x[N], y[N]	Resources
A, B	A[N], B[N]	Products of production
s, S*	s[N], sAB[N]	Squares
a11, a12, a21, a22	a11, a12, a21, a22	Specific consumptions
k	k	k = a11a22 – a12a21
C, b	C, b	Coefficients
	ratio[i] = sAB[i] / s[i]	Area ratio
I[N]	disp[N]	Disproportion
	q	Degree of impact on specific consumptions
	start	Distortion start
	final	End distortion

4. MANUAL

The program was written using C++ programming language so therefore an IDE built for running the program is needed.

For the test case, the program Dev-C++ was used for the best result.

Size of program [kama_affin.cpp] - 1,267 bytes

Size on disk - 4,096 bytes

After running the program, there is an output on the screen which prints the disproportionality values and two text files are created where all the results are written to.

File names – “affin_res.txt” and “affin_excel.txt”

File size - 4,096 bytes.

5. TEST CASE

Initial data for testing:

$a_{11} = 4$, $a_{12} = 2$, $a_{21} = 2$, $a_{22} = 2.5$

$N = 24$

$h = 0.5$

$C = 15$

$b = 0.95$

$q = 0.001$

start = 10

final = 15

Several variants of influence on the ongoing process are investigated with a degree of influence on it of 0.1% (q = 0.001). The results are shown in tables and graphics.

Variant 1

The appearance of an excess amount of resource x proportionally increases its unit costs for the production of both products:

$a_{11} = a_{11} + qx\ [j];$

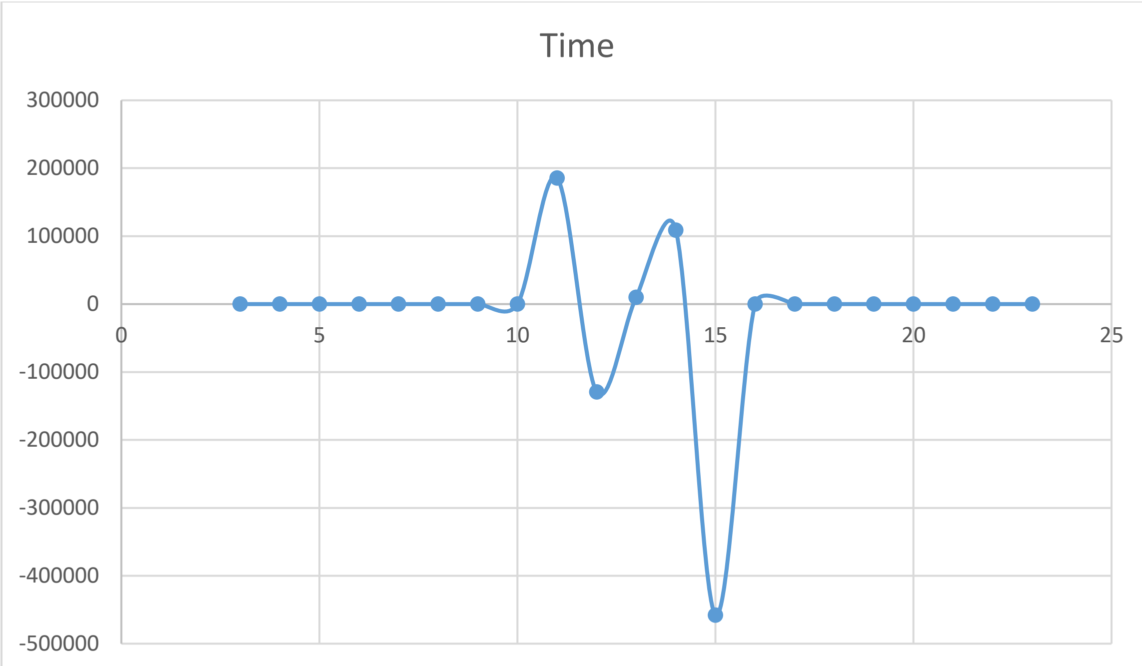
$a_{22} = a_{22} + qx\ [j];$

The results are shown in Table 5.1 and Graph 5.1

i	s	sAB	ratio	disp
3	-0,04677	-0,2806	6	2,76E-12
4	-0,0297	-0,1782	6	-1,09E-11
5	-0,02175	-0,13053	6	7,63E-12
6	-0,01714	-0,10283	6	5,47E-12
7	-0,01412	-0,08473	6	-6,10E-12
8	-0,01199	-0,07197	6	-1,93E-13
9	-0,01042	-0,0625	6	-1,48E-11

10	-0,0092	-0,0552	6	2,41E-11
11	-0,00823	2,85	-346,107	185,819
12	-0,00745	0,746364	-100,235	-129,101
13	-0,00679	0,812547	-119,591	10,121
14	-0,00625	0,877636	-140,523	10,9062
15	-0,00578	-4,27835	740,571	-457,711
16	-0,00537	-0,03311	6,16313	380,52
17	-0,00502	-0,03094	6,16312	2,21E-10
18	-0,00471	-0,02903	6,16312	5,24E-11
19	-0,00444	-0,02734	6,16313	-3,83E-10
20	-0,00419	-0,02583	6,16313	9,79E-11
21	-0,00397	-0,02447	6,16312	1,24E-10
22	-0,00377	-0,02325	6,16313	-4,59E-10
23	-0,00359	-0,02214	6,16313	1,98E-10

Table 5.1 – The test results are shown in the table above.



Graph 5.3 – The test results are shown in the graph above.

Variant 2

The appearance of an excess amount of resource y proportionally increases its unit costs for the production of both products:

$a_{11} = a_{11} + qy\ [j];$

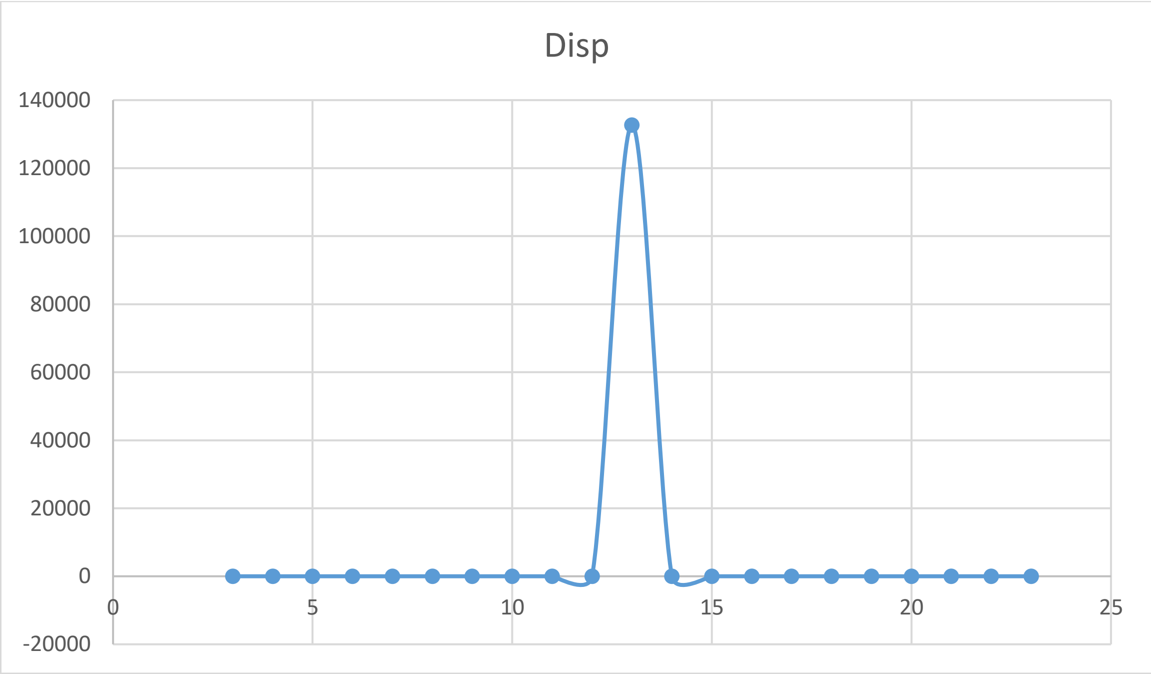
$a_{22} = a_{22} + qy\ [j];$

The results are shown in Table 5.2 and Graph 5.2

i	S	sAB	ratio	disp
3	-0,04677	-0,2806	6	2,76E-12
4	-0,0297	-0,1782	6	-1,09E-11

5	-0,02175	-0,13053	6	7,63E-12
6	-0,01714	-0,10283	6	5,47E-12
7	-0,01412	-0,08473	6	-6,10E-12
8	-0,01199	-0,07197	6	-1,93E-13
9	-0,01042	-0,0625	6	-1,48E-11
10	-0,0092	-0,0552	6	2,41E-11
11	-0,00823	39,8784	-4844,07	2559,55
12	-0,00745	10,6361	-1428,41	-1793,48
13	-0,00679	11,43	-1955,28	132,749
14	-0,00625	12,2136	10009,5	142,4
15	-0,00578	-57,8261	8,34069	-6215,64
16	-0,00537	-0,04481	8,34069	5181,94
17	-0,00502	-0,04187	8,34069	-4,2E-10
18	-0,00471	-0,03929	8,34069	-5,94E-11
19	-0,00444	-0,037	8,34069	4,68E-10
20	-0,00419	-0,03495	8,34069	-4,71E-11
21	-0,00397	-0,03312	8,34069	2,33E-10
22	-0,00377	-0,03146	8,34069	-2,01E-10
23	-0,00359	-0,02996	8,34069	1E-10

Table 5.2 – The test results are shown in the table above.



Graph 5.2 – The test results are shown in the graph above.

Variant 3

The appearance of an excess amount of both resources x and y proportionally increases their unit costs for the production of both products:

$a_{11} = a_{11} + qx\ [j];$

$a_{12} = a_{12} + qx\ [j];$

$a_{21} = a_{21} + qx\ [j];$

$a_{22} = a_{22} + qx\ [j];$

$a_{11} = a_{11} + qy\ [j];$

$a_{12} = a_{12} + qy\ [j];$

$a_{21} = a_{21} + qy\ [j];$

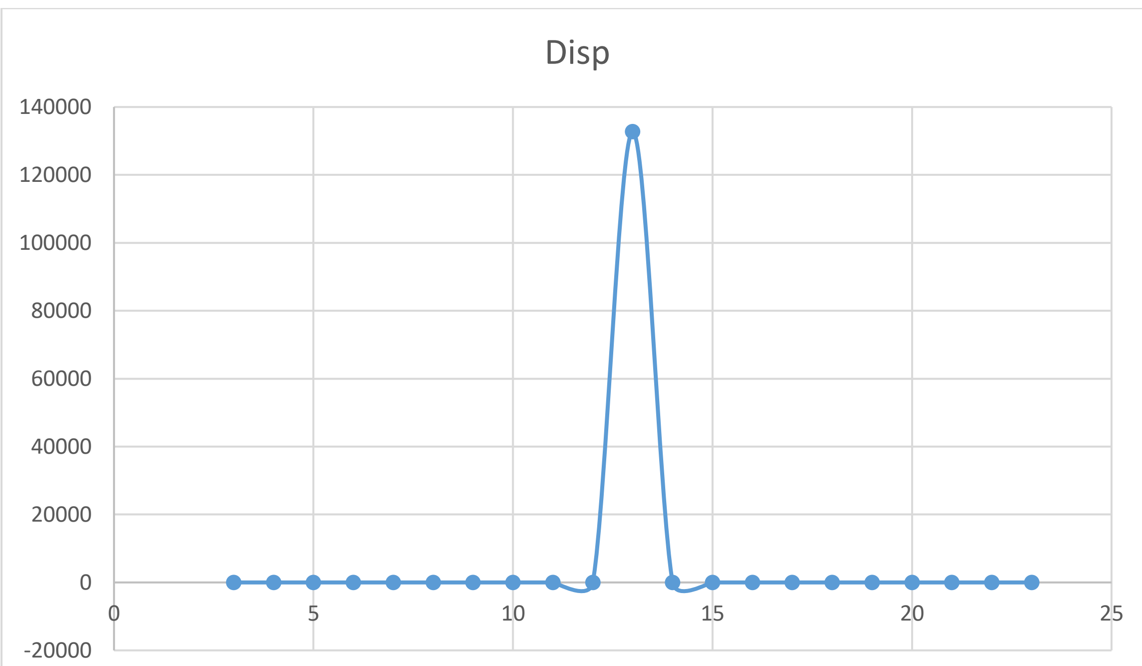
$a_{22} = a_{22} + qy\,[j];$

The results are shown in Table 5.3 and Graph 5.3

i	S	sAB	ratio	disp
3	-0,04677	-0,2806	6	2,76E-12
4	-0,0297	-0,1782	6	-1,09E-11
5	-0,02175	-0,13053	6	7,63E-12
6	-0,01714	-0,10283	6	5,47E-12
7	-0,01412	-0,08473	6	-6,10E-12
8	-0,01199	-0,07197	6	-1,93E-13
9	-0,01042	-0,0625	6	-1,48E-11
10	-0,0092	-0,0552	6	2,41E-11
11	-0,00823	-1,07535	130,623	2559,55
12	-0,00745	-0,32815	44,0693	-1793,48
13	-0,00679	-0,34626	50,9624	132,749
14	-0,00625	-0,36476	58,4039	142,4
15	-0,00578	1,44979	-250,955	-6215,64
16	-0,00537	-0,03291	6,125	5181,94
17	-0,00502	-0,03075	6,125	-4,2E-10

18	-0,00471	-0,02885	6,125	-5,94E-11
19	-0,00444	-0,02717	6,125	4,68E-10
20	-0,00419	-0,02567	6,125	-4,71E-11
21	-0,00397	-0,02432	6,125	2,33E-10
22	-0,00377	-0,0231	6,125	-2,01E-10
23	-0,00359	-0,022	6,125	1E-10

Table 5.3 – The test results are shown in the table above.



Graph 5.3 – The test results are shown in the graph above.

RESULT ANALYSIS

In all the above cases, in the interval from i = 11 to i = 15, there is a deterioration in the conditions of the process, which leads to an increase in the specific consumptions of resources. This leads to a violation of the affine relationship between the input and output parameters. As a result, disproportionality (8) ceases to be zero.

This indicates that the algorithm and the computer program are working correctly.

CONCLUSION

An algorithm and a computer program have been developed for detecting at the current time the fact of the appearance of a deviation of the specific consumption of raw materials from the optimal values.

Their suitability has been verified with test cases.

The proposed method and computer program can be used for operational control of chemical-technological and other production processes.

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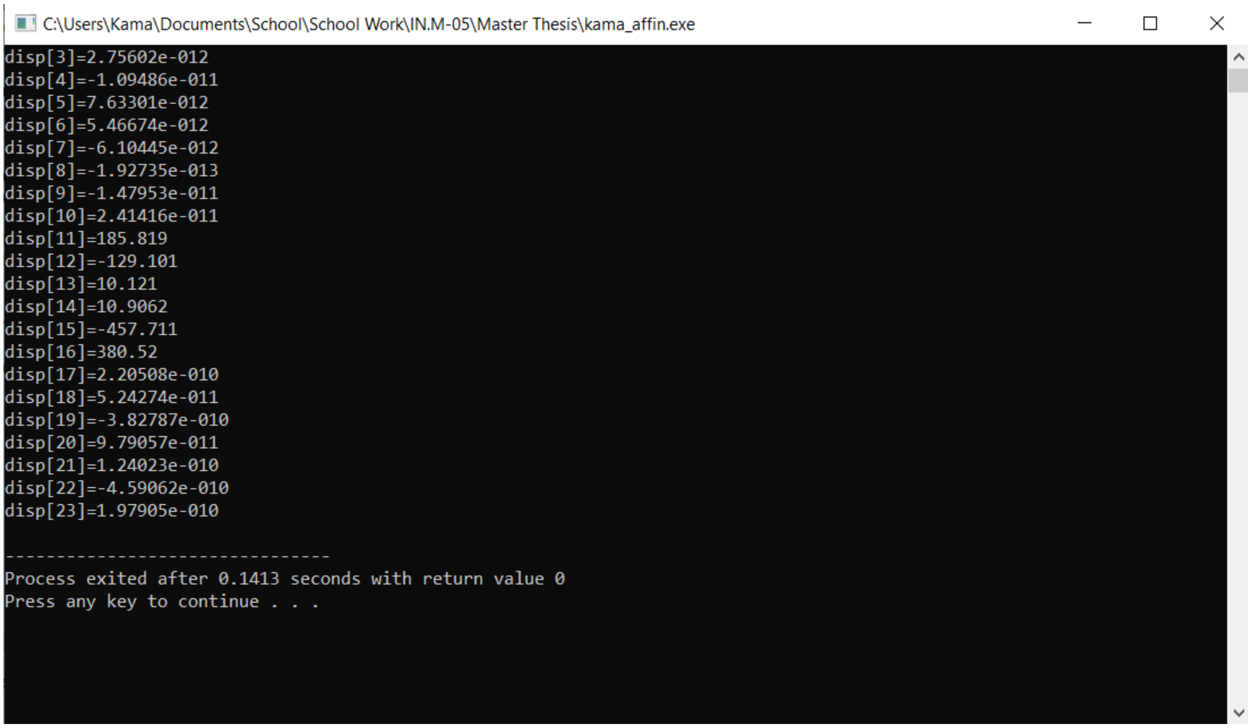
ADDITION

This is the program code for kama_affin.cpp:

```
#include <iostream>
#define N  24
#include <math.h>

using namespace std;

int main()
{
	double a11 = 4, a12 = 2, a21 = 2, a22 = 2.5, h = 0.5,  C = 15, b = 0.95, q = 
0.001;
	double x[N], y[N], A[N], B[N], s[N], sAB[N], ratio[N], disp[N];

	FILE *p = fopen("affin_res.txt", "w");
	FILE *p1 = fopen("affin_excel.txt", "w");



	int start = 10, final = 15;

	for (int j = 0; j < N; j++)
	{
		x[j] = j * h;
		y[j] = C * pow(x[j], b);
```

```
        if (j > start && j < final)
        {
            a11 = a11 + q * x[j];
            a22 = a22 + q * x[j];
        }

        A[j] = a11 * x[j] + a12 * y[j];
        B[j] = a21 * x[j] + a22 * y[j];
    }
    for (int i = 2; i < N; i++)
    {
        s[i] = 0.5 * ((x[i - 2] - x[i - 1]) * (y[i - 2] + y[i - 1]) + (x[i - 1] - x[i]) *
(y[i - 1] + y[i]) + (x[i] - x[i - 2]) * (y[i] + y[i - 2]));
        sAB[i] = 0.5 * ((A[i - 2] - A[i - 1]) * (B[i - 2] + B[i - 1]) + (A[i - 1] -
A[i]) * (B[i - 1] + B[i]) + (A[i] - A[i - 2]) * (B[i] + B[i - 2]));
        ratio[i] = sAB[i] / s[i];
    }
    for (int i = 3; i < N; i++)
    {
        disp[i] = (sAB[i - 1] + sAB[i]) / (s[i - 1] + s[i]) - sAB[i] / s[i];
        printf("disp[%i]=%lg\n", i, disp[i]);
        fprintf(p, " %i                    %lg                  %lg
    %lg                  %lg\n", i, s[i], sAB[i], ratio[i], disp[i]);
        fprintf(p1, "%lg\n", disp[i]);
    }
}
```

SCREENSHOT OF OUTPUT ON SCREEN



Picture – Screenshot of program disproportionality values.