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The influence of robotization on the reliability of the production process in the bakery industry

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ABSTRACT:

The purpose of the article is to determine the impact of robotization on the reliability of the production line of micro and small companies in the bakery industry based on research carried out in the period from 02/01/2016 to 31/12/2018. The author presented the issues of measuring the reliability of a robotized production system, specified all machines after robotization, marking them appropriately in the process, which was necessary for further calculations. Then, the reliability calculations of the selected robotized system design (draft version — TRAY) based on the probabilistic concept were presented. The rest of the article presents a diagram of the reliability of the robotized bread production process using one WPH1 line together with the final results which showed that after the introduction of the robotized system, the reliability of machines on the bread production line improved by 6%.

Wpływ robotyzacji na niezawodność procesu produkcyjnego w branży piekarniczej

Słowa kluczowe: niezawodność procesu produkcyjnego, robotyzacja, koncepcja probabilistyczna

STRESZCZENIE:

Celem artykułu jest ustalenie wpływu robotyzacji na niezawodność linii produkcyjnej mikro i małych przedsiębiorstw w branży piekarniczej na podstawie badań wykonanych w okresie 2016.01.02-2018.12.31. Autor przedstawił problematykę opomiarowania niezawodności zrobotyzowanego systemu produkcyjnego, wyszczególnił wszystkie maszyny po robotyzacji, oznaczając je odpowiednio w procesie, co było niezbędne do dalszych obliczeń. Następnie zostały przedstawione obliczenia niezawodności wybranego projektu systemu zrobotyzowanego (wersja robocza – TRAY), oparte na koncepcji probabilistycznej. W dalszej części artykułu został zaprezentowany schemat niezawodności zrobotyzowanego procesu produkcyjnego chleba z wykorzystaniem jednej linii WPH1 wraz z końcowymi wynikami, które wykazały, że po wprowadzeniu systemu zrobotyzowanego niezawodność pracy maszyn na linii produkcyjnej chleba uległa poprawie o 6%.

1. INTRODUCTION

The era of progressive globalisation and increased pressure of competitiveness on the part of the market have resulted in an unprecedented technical and technological progress, both at the level of technological machinery, auxiliary operations equipment, as well as the communication and control systems of the generating systems, becoming an important element having an impact on the direction of development of micro and small companies in the bakery industry (MSCBI). The breakthrough moment having a qualitative impact on significant changes in the direction of robotization of production lines is the occurrence of industrial robots in MSCBI.

Robotization is a significant technological step forward for MSCBI. The decisive benefits of its implementation and application in the production processes are mainly in terms of direct impact of reliability on the production lines in the bakery industry [1]. The definition of reliability may cover different requirements described by the technical, economic and sociological characteristics of the facilities [4]. The following types of reliability are distinguished: – technical reliability which takes into account technical characteristics; – technical and economic reliability which takes into account technical and economic characteristics; – global reliability which takes into account technical, economic and social characteristics of the facilities [5].

This article presents calculations of the reliability of robotization based on the probabilistic concept on an example of the bakery X operating within the MSCBI group.

On the basis of own tests (carried out during the period from 02/01/2016 to 31/12/2018) and actual data from the operation of the robotized system, the author determined its impact on the course of reliability during the production process for one bread production line. This impact was determined on the basis of available probabilistic models, such as: exponential distribution, Weibull distribution, gamma distribution, normal standardised distribution, and normal logarithmic distribution [2, 3].

2. DESCRIPTION OF THE ENTIRE MACHINE FACILITIES OF THE BAKERY X AFTER ROBOTIZATION

The list of all machines used on the production line after robotization is included in Table 1. It provides:

1. A list and division of machines (before robotization) in the traditional production system.
2. A list of two designed robotized systems including:

a) robotized system for tray feeding (draft version — TRAY) for use in the bakery industry based on the use of a multi-purpose industrial robot with a wide range of movement (draft version — ROB1) with a controller (draft version — CON1) for production support processes;

b) robotized system for palletisation and depalletisation (draft version — PACK) for use in the bakery industry based on the use of a multi-purpose industrial robot with a wide range of movement (draft version — ROB2) with a controller (draft version — CON2) for production support processes with X-RAY system with a detector to sense pollutants in the bakery products, such as metal, stones, glass, plastics, which will result in complete elimination of the defective products.

Table 1 List of all machines in the bakery X after robotization and their designations in the process

Machine		**Symbol (process designation)**
1. Silo unit	(4 pcs)	A1, A2, A3, A4
2. Dosing systems	(2 pcs)	B1, B2
3. Spiral mixer unit	(3 pcs)	C1, C2
4. Mobile kneading trough unit	(7 pcs)	D1, D2, D3, D4, D5, D6
Bread production lines	(1 pc)	WPH1
1. Kneading trough tippler unit	(2 pcs)	E1, E2
2. Suction and pumping divider unit	(2 pcs)	F1, F2
3. Conical rounder unit	(2 pcs)	G1, G2
4. Intermediate proofing unit	(2 pcs)	H1, H2
5. Dough stretcher unit	(2 pcs)	I1, I2
New robotized system TRAY		**TRAY**
Processes for placing chunks on trays and trolleys		
1. Proofing unit		J1, J2
2. Thermal and oil oven unit	(17 pcs)	ZP 1-17
3. Cooldown process		
4. Slicer and clipper unit	(2 pcs)	K1, K2
New robotized system PACK		**PACK**
+ X-ray machine		**X-RAY**

Source: Own study based on tests performed in the bakery X

3. DESIGN CONCEPT OF THE ROBOTIZED SYSTEM FOR THE BAKERY INDUSTRY

Due to the restriction of the maximum number of pages in this article, the author only presented a design of a robotized TRAY system with calculations.

The essence of the design will be to adapt a multi-purpose industrial robot with a wide range of movement (ROB1) to production support processes (feeding of trays for the production process) and associated processes, such as washing of baking containers and cleaning of trays in the bakery.

The concept of the robotized TRAY system will consist in designing an innovative process of tray feeding for use in the bakery industry, based on the use of a multi-purpose industrial robot with a wide range of movement (ROB1) with a controller (CON1) for production support processes, among others, by feeding trays for laying dough chunks, feeding trays with baked products for their unloading to the transporter, washing of trolleys with the use of a Karcher pressure lance attached to the robot's wrist (pressure: 200 bar), washing of baking containers taken from and put on Euro-pallets with a fixed lance, designating a safe manual work area for trays fed by the robot, and optional functions of bread decoration and setting of individual functions (sprinkling with grains, notching of dough chunks, applying of sauces).

4. RELIABILITY ANALYSIS OF THE ROBOTIZED TRAY SYSTEM

The reliability analysis of the TRAY system will involve the use of probabilistic models in calculations for individual core components of the system, which are:

1. Robot ROB1 with controller CON1 — designated as $\mathbf{RK_{T1}}$.
2. Set of belt conveyors (3 pcs) — designated as $\mathbf{T_{T1}}$, $\mathbf{T_{T2}}$, $\mathbf{T_{T3}}$.
3. Proximity sensors (2 pcs) transmitter + receiver, and 4 proximity switches — designated as $\mathbf{CZ_{T1}}$, $\mathbf{CZ_{T2}}$, $\mathbf{CZ_{T3}}$, $\mathbf{CZ_{T4}}$, $\mathbf{CZ_{T5}}$, $\mathbf{CZ_{T6}}$.
4. Mobile acid-resistant barrier (separating the robot from the operator) — designated as $\mathbf{K_{T1}}$.
5. Solenoid valves (4 pcs on gates + 3 pcs on operator table) — designated as $\mathbf{E_{T1}}$, $\mathbf{E_{T2}}$, $\mathbf{E_{T3}}$, $\mathbf{E_{T4}}$, $\mathbf{E_{T5}}$, $\mathbf{E_{T6}}$, $\mathbf{E_{T7}}$.
6. Operator table (for laying of chunks, 4 levels — robot handles in pairs) designated as $\mathbf{S_{T1}}$.

During the analysis of the reliability structure of the designed robotized TRAY system, there was a list of defects (errors) in the tests which should be taken into account by dividing them into human, energy and technical factors.

The structure of the production system may sometimes be covered by process secrecy.

In the case in question, a detailed process specification of production streams was performed.

Table 2 List of diagnosed and potential failures in terms of human (operator) factor

–	when the operator provides the TRAY slot with trolleys, they are erroneously leveled, which causes incorrect synchronisation of their position for the robot	**Czl-1**
–	when the operator provides the TRAY slot with trays, they are erroneously leveled, which causes incorrect synchronisation of their position for the robot	**Czl-2**
–	unauthorised operator entry into the robot's work area	**Czl-3**
–	mechanical damage of the proximity detector(s) caused by the operator	**Czl-4**
–	mechanical damage of the solenoid valve(s) caused by the operator	**Czl-5**
–	mechanical damage of the barrier caused by the operator	**Czl-6**
–	mechanical damage of one set / all sets of belt conveyors caused by the operator	**Czl-7**

Source: Own study based on tests performed in the bakery X

Table 3 List of diagnosed and potential failures in terms of energy factor

– if the power supply is off, the robot stops and when the power supply is on, the robot returns to 0 (time loss)	**Cze-1**
– lack of power supply results in the robot's loss of position synchronisation on the encoder	**Cze-2**
– lack of power supply causes all proximity detectors to stop	**Cze-3**
– lack of power supply causes all solenoid valves to stop	**Cze-4**
– lack of power supply causes acid-resistant barrier to stop	**Cze-5**
– lack of power supply causes all belt conveyors to stop	**Cze-6**

Source: Own study based on tests performed in the bakery X

Table 4 List of diagnosed and potential failures in terms of technical (robot communication) factor

sensor does not detect obstacles (dirt, calibration)	**Czt-1**
the reading of the sensor is random	**Czt-2**
the robot goes beyond its designated work area (hazard to the operator's life)	**Czt-3**
possibility of seizure of the robot's servomotor due to excessive lifting capacity	**Czt-4**
system overload caused by increased robot operating temp.	**Czt-5**
overloading or seizing of motor(s) in the belt conveyor unit	**Czt-6**
overloading or seizing of the barrier motor	**Czt-7**
disturbances in opening and closing of the solenoid valves	**Czt-8**

Source: Own study based on tests performed in the bakery X

The indicated factors will be adequately allocated to the test analysis when calculating the reliability of the robotized TRAY system. In this article, the author presented a part of the study concerning <u>only one core component of the system — the robot ROB1 together with the controller CON1</u> — which is presented in Table 5.

Table 5 Information concerning the operation of the robot ROB1 with the controller CON1

Machine name	**Robot ROB1 with controller CON1**
Daily operation time Annual operation time (2018)	8 hours per day 8 h × 312 days = 2496 h
List of diagnosed failures	Overall malfunction time (years)
Czl-1	2017
Czl-2	2017
Czl-3	2017, 2018
Cze-1	None
Cze-2	2017, 2018
Czt-3	None
Czt-4	None
Czt-5	2018
Year of purchase of the machine	2016
Symbol in the process	$\mathbf{RK_{T1}}$
Expected duration of failure-free operation	3 years – 18,000 hours – test period (2016-2018)

Source: Own study based on tests performed in the bakery X

The reliability calculations for the robot ROB1 with the controller CON1 are presented below.

Exponential distribution

t = number of years from start-up of the machine until the end of 2018 × average number of working days a year × daily number of hours of operation of the machine

$$t = 3 \times 312 \times 8 = 7488$$

E(t) = expected duration of failure-free operation (for the three-year test)

$$E(t) = \frac{1}{\lambda}$$

$$\lambda = \frac{1}{18000} = 0.00005555$$

$$R(t) = e^{-\lambda t} = e^{-0.00005555*7488} \approx \mathbf{0.6597}$$

E(t) = mean operation time to failure on the basis of the obtained data

E(t) = 2496 (2017) + 4992 (2018) / 2 = **3744**

$$\lambda = \frac{1}{3744} = 0.0002671$$

$$R(t) = e^{-\lambda t} = e^{-0.0002671*7488} \approx \mathbf{0.1353}$$

For exponential distribution of the reliability function R(t), the expected duration of failure-

-free operation of the machine is 65.97%. The probability of proper operation of the machine in this reliability function E(t) is 13.53%.

Weibull distribution

p	E(t) Expected duration of failure-free operation	E(t) Mean operation time to failure on the basis of the obtained data
1	R(t) = e⁻ $(\frac{7488}{18000})^1 \approx 0.6597$	R(t) = e⁻ $(\frac{7488}{3744})^1 \approx 0.1353$
2	R(t) = e⁻ $(\frac{7488}{18000})^2 \approx 0.8411$	R(t) = e⁻ $(\frac{7488}{3744})^2 \approx 0.0183$
3	R(t) = e⁻ $(\frac{7488}{18000})^3 \approx 0.9305$	R(t) = e⁻ $(\frac{7488}{3744})^3 \approx 0.0003$

For Weibull distribution of the reliability function R(t), the expected duration of failure-free operation of the machine is for indicators p-1 = 65.97%, p-2 = 84.11%, p-3 = 93.05%. The probability of proper operation of the machine in this reliability function E(t) is for indicators p-1 = 13.53%, p-2 = 1.83%, p-3 = 0.03%.

Gamma distribution

E(t) expected duration of failure-free operation

$$E(T) = \frac{p}{b}$$

p = 1 $\quad 18{,}000 = \frac{1}{b} \quad$ b = 0.00005555

$$R(t) = 1 - F(t) = \exp(-bt)\sum_{i=0}^{p-1}\frac{(bt)^i}{i!} = 1 - \exp(-bt)\sum_{i=p}^{\infty}\frac{(bt)^i}{i!}$$

$R(t) = 1 - e^{(0.00005555*7488)} * [\frac{(0.00005555*7488)^1}{1}] \approx \mathbf{0.7672}$

p=2 $\quad 18{,}000 = \frac{2}{b} \quad$ b= 0.00011111

$R(t) = 1 - e^{(0.00011111*7488)} * [\frac{(0.00011111*7488)^1}{1} + \frac{(0.00011111*7488)^2}{2}] \approx \mathbf{0.4873}$

p=3 $\quad 18{,}000 = \frac{3}{b} \quad$ b= 0.00016666

$R(t) = 1 - e^{(0.00016666*7488)} * [\frac{(0.00016666*7488)^1}{1} + \frac{(0.00016666*7488)^2}{2} + \frac{(0.00016666*7488)^3}{6}] \approx \mathbf{0.3252}$

t) mean operation time to failure on the basis of the obtained data

$$R(t) = 1 - F(t) = \exp(-bt)\sum_{i=0}^{p-1}\frac{(bt)^i}{i!} = 1 - \exp(-bt)\sum_{i=p}^{\infty}\frac{(bt)^i}{i!}$$

p = 1 $\quad 3744 = \frac{1}{b} \quad$ b = 0.0002671

$R(t) = 1 - e^{(-0.0002671*7488)} * [\frac{(0.0002671*7488)^1}{1}] \approx \mathbf{0.7294}$

p = 2 $\quad 3744 = \frac{2}{b} \quad$ b = 0.0005342

$R(t) = 1 - e^{(-0.0005342*7488)} * [\frac{(0.0005342*7488)^1}{1} + \frac{(0.0005342*7488)^2}{2}] \approx \mathbf{0.7804}$

p = 3 $\quad 3744 = \frac{3}{b} \quad$ b = 0.0008013

$R(t) = 1 - e^{(-0.0008013*7488)} * [\frac{(0.0008013*7488)^1}{1} + \frac{(0.0008013*7488)^3}{6}] \approx \mathbf{0.8499}$

For gamma distribution of the reliability function R(t), the expected duration of failure-free operation of the machine is for indicators p-1 = 76.72%, p-2 = 48.73%, p-3 = 32.52%. The probability of proper operation of the machine in this reliability function E(t) is for indicators p-1 = 72.94%, p-2 = 78.04%, p-3 = 84.99%.

Normal distribution

m = expected duration of failure-free operation

$$\delta = \sqrt{\frac{\sum(x-m)^2}{n}} \approx \mathbf{14{,}309.62}$$

for n = 2, m = 18,000
x_1 = 2496 , x_2 = 4994,

$$yt = \frac{t-t_0}{\delta} = \frac{7488-18000}{14309.62} \approx -\mathbf{0.7346}$$

$$y_0 = -\frac{t_0}{\delta} = -\frac{18000}{14309.62} \approx -\mathbf{1.2579}$$

$$R(t) = \frac{1-\phi(yt)}{1-\phi(y_0)} = \frac{1-(-0.7346)}{1-(-1.2579)} \approx \mathbf{0.7682}$$

m = mean operation time to failure on the basis of the obtained data

$$\delta = \sqrt{\frac{\sum(x-m)^2}{n}} \approx \mathbf{1249.01}$$

for n = 2, m = 3744
x_1 = 2496, x_2 = 4994,

$$yt = \frac{t-t_0}{\delta} = \frac{7488-3744}{1249.01} \approx \mathbf{2.9976}$$

$$y_0 = -\frac{t_0}{\delta} = -\frac{3744}{1249.01} \approx -\mathbf{2.9976}$$

$$R(t) = \frac{1-\phi(yt)}{1-\phi(y_0)} = \frac{1-(-2.9976)}{1-(-2.9976)} \approx \mathbf{1}$$

For normal distribution of the reliability function R(t), the expected duration of failure-free operation of the machine is 76.82%. The probability of proper operation of the machine in this reliability function E(t) is 100%.

Normal logarithmic distribution

m = expected duration of failure-free operation for n = 2, m = ln 18,000 ≈ 9.80, x = ln 7488 ≈ 8.92

x_1 = ln 2496 ≈ 7.8224 ; x_2 = ln 4994 ≈ 8.5160;

$$\delta = \sqrt{\frac{\sum(x-m)^2}{n}} \approx \mathbf{1.6673}$$

$$yt = \frac{t-t_0}{\delta} = \frac{8.92-9.80}{1.6673} \approx \mathbf{-0.5278}$$

$$y_0 = -\frac{t_0}{\delta} = -\frac{9.80}{1.6673} \approx \mathbf{-5.8778}$$

$$R(t) = \frac{1-\phi(yt)}{1-\phi(y_0)} = \frac{1-(-0.5278)}{1-(-5.8778)} \approx \mathbf{0.2221}$$

m = mean operation time to failure on the basis of the obtained data

x_1 =ln 2496 ≈ 7.8224 ; x_2 = ln 4994 ≈8.5160;

$$\delta = \sqrt{\frac{\sum(x-m)^2}{n}} \approx \mathbf{0.3521}$$

$$yt = \frac{t-t_0}{\delta} = \frac{8.92-8.23}{0.3521} \approx \mathbf{1.9597}$$

$$y_0 = -\frac{t_0}{\delta} = -\frac{8.23}{0.3521} \approx \mathbf{-23.3741}$$

$$R(t) = \frac{1-\phi(yt)}{1-\phi(y_0)} = \frac{1-(1.9597)}{1-(-23.3741)} \approx \mathbf{0.0394}$$

For normal logarithmic distribution of the reliability function R(t), the expected duration of failure-free operation of the machine is 22.21%. The probability of proper operation of the machine in this reliability function E(t) is 3.94%.

5. RELIABILITY OF THE ROBOTIZED BREAD PRODUCTION PROCESS USING ONE WPH1 LINE

Figure 2 shows an example diagram of a robotized bread production process using one WPH1 line. The input data were taken from the author's own tests performed during the period from 02/01/2016 to 31/12/2018 to calculate the reliability of the robotized bread production process using the entire WPH1 line, i.e.:

1. Silo unit

RA1 = 0.9995, RA2 = 0.9995, RA3 = 0.9995, RA4 = 0.9995, i.e. (RA = 0.9995)

2. Dosing systems

RB1 = 0.9995, RB2 = 0.9995, i.e. (RB = 0.9995)

3. Spiral mixer unit

RC1 = 0.9993, RC2 = 0.9993, i.e. (RC = 0.9993)

4. Mobile kneading trough unit

RD1 = 0.9993, RD2 = 0.9993, RD3 = 0.9993, RD4 = 0.9993, i.e. (RD = 0.9993)

WPH1 bread production line

RE1 = 0.9993, RF1 = 0.9993, RG1 = 0.9993, RH1 = 0.9993, RI1 = 0.9993, i.e. (WPH1 = 0.9993)

5. Newly designed robotized TRAY system

RK_{T1} = 0.9881, RT_{T1} = 0.9695, RT_{T2} = 0.9695, RT_{T3} = 0.9695, RCZ_{T1} = 0.9097, RCZ_{T2} = 0.9097, RCZ_{T3} = 0.9097, RCZ_{T5} = 0.9097, RCZ_{T6} = 0.9097, RK_{T1} = 0.9695, RE_{T1} = 0.9881, RE_{T2} = 0.9881, RE_{T3} = 0.9881, RE_{T4} = 0.9881, RE_{T5} = 0.9881, RE_{T6} = 0.9881, RE_{T7} = 0.9881

6. Process for placing chunks (POK1) on trays and trolleys

7. Proofing unit

RJ1 = 0.9993, RJ2 = 0.9993, i.e. (RJ = 0.9993)

8. Thermal and oil oven unit

RZP1 = 0.9964, RZP2 = 0.9964, RZP3 = 0.9964, RZP4 = 0.9964, RZP5 = 0.9964, RZP6 = 0.9964, RZP7 = 0.9964, RZP8 = 0.9964, RZP9 = 0.9964, RZP10 = 0.9964

9. Cooldown process (PW)

10. Newly designed robotized PACK system

RK_{P1} = 0.9881, T_{P1} = 0.9695, CZ_{P1} = 0.9097, CZ_{P2} = 0.9097, CZ_{P3} = 0.9097, CZ_{P4} = 0.9097, K_{P1} = 0.9695, E_{P1} = 0.9881, E_{P2} = 0.9881, E_{P3} = 0.9881, E_{P4} = 0.9881, E_{P5} = 0.9881, E_{P6} = 0.9881, E_{P7} = 0.9881, E_{P8} = 0.9881

11. Slicer and clipper unit

RK1 = 0.9993, RK2 = 0.9993, i.e. (RK = 0.9993)

12. Newly designed

X-RAY RX-RAY = 0.9881

Calculations of the reliability of the robotized bread production process using one WPH1 line

Data:

[1-(1-RA1) × (1-RA2) × (1-RA3) × (1-RA4)] ×
[1-(1-B1) × (1-B2)] ×
RC1 × [1-(1-RD1) × (1-RD2)]
RC2 × [1-(1-RD4) × (1-RD5)]
[1-(1-RE1) × (1-RF1) × (1-RG1) × (1-RH1) × (1-RI1]
[1-(1-RE2) × (1- RF2) × (1-RG2) × (1-RH2) × (1-RI2]
[1-(1-RK_{T1}) × (1-RT_{T1}) × (1-RT_{T2}) × (1-RT_{T3}) × (1-RCZ_{T1}) × (1-RCZ_{T2}) × (1-RCZ_{T3}) × (1-RCZ_{T4})×(1-RCZ_{T5})×(1-RCZ_{T6})×(1-RK_{T1})×(1-RE_{T1})× (1-RE_{T2}) × (1-RE_{T3}) × (1-RE_{T4}) × (1-RE_{T5}) × (1-RE_{T6}) × (1-RE_{T7})] ×
[1-(1-RJ) × (1-RJ2)] ×
[1-(1-RZP1) × (1-RZP2) × (1-RZP3) × (1-RZP4) × (1-RZP5) × (1-RZP6) × (1-RZP7) × (1-RZP8) × (1-RZP9) × (1-RZP10] ×

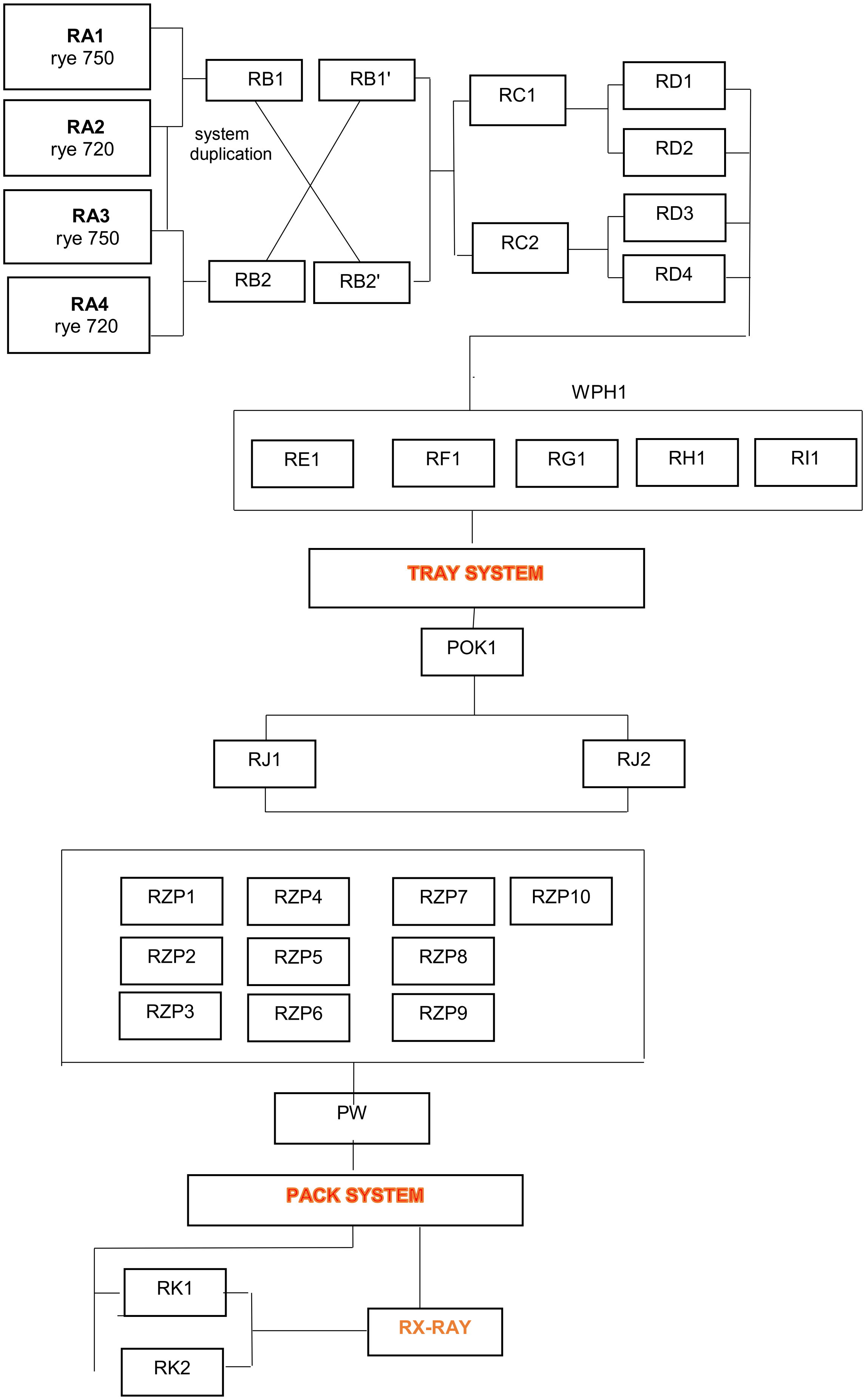

Figure 2 Reliability diagram of the robotized bread production process using one WPH1 line
Source: Own study based on tests performed in the bakery X

$[1-(1-RK_{P1}) \times (1-RT_{P1}) \times (1-RCZ_{P1}) \times (1-RCZ_{P2}) \times (1-RCZ_{P3}) \times (1-RCZ_{P4}) \times (1-RK_{P1}) \times (1-RE_{P1}) \times (1-RE_{P2}) \times (1-RE_{P3}) \times (1-RE_{P4}) \times (1-RE_{P5}) \times (1-RE_{P6}) \times (1-RE_{T7}) \times (1-RE_{T7})]$

[1-(1-RK1) × (1-RK2)] × RX-RAY

Further part of the calculations (result substitution)

[1-(1-0.9995) × (1-0.9995) × (1-0.9995) × (1-0.9995)] ×

[1-(1-0.9995) × (1-0.9995)] ×

0.9993 × [1-(1-0.9993) × (1-0.9993)]

0.9993 × [1-(1-0.9993) × (1-0.9993)]

[1-(1-0.9993) × (1-0.9993) × (1-0.9993) × (1-0.9993)]

[1-(1-0.9993) × (1-0.9993) × (1-0.9993) × (1-0.9993)]

[1-(1-0.9881)×(1-0.9695)×(1-0.9695)×(1-0.9695)× (1-0.9097) × (1-0.9097) × (1-0.9097) × (1-0.9097) × (1-0.9097) × (1-0.9097) × (1-0.9695) × (1-0.9881) × (1-0.9881) × (1-0.9881) × (1-0.9881) × (1-0.9881) × (1-0.9881) × (1-R0.9881)] ×

[1-(1-0.9993) × (1-0.9993)] ×

[1-(1-0.9964) × (1-0.9964) × (1-0.9964) × (1-0.9964) × (1-0.9964) × (1-0.9964) × (1-0.9964) × (1-0.9964) × (1-0.9964) × (1-0.9964)] ×

[1-(1-0.9881)×(1-0.9695)×(1-0.9097)×(1-0.9097)× (1-0.9097) × (1-0.9097) × (1-0.9695) × (1-0.9881) × (1-0.9881) × (1-0.9881) × (1-0.9881) × (1-0.9881) × (1-0.9881) × (1-0.9881)] ×

[1-(1-0.9993) × (1-0.9993)] × 0.9401

R = 0,9401

The calculations indicate that the reliability of the bread production process with the use of a robotized WPH1 line is 0.9401. This result can be interpreted so that in the tested bakery, the reliability of operation of the machinery on the production line after the introduction of the robotized system in this configuration amounted to 94.01%.

6. CONCLUSIONS

The author's tests carried out from 02/01/2016 to 31/12/2018 showed that in the bakery X:

a) The reliability of the traditional bread production process using one WPH1 line was 0.8804. This result indicates that in the tested bakery, the reliability of operation of machinery on the production line in this configuration amounted to 88.04%.

b) The reliability of the bread production process with the use of a robotized WPH1 line was 0.9401. This means that in the tested bakery, the reliability of operation of the machinery on the production line after the introduction of the robotized system in this configuration amounted to 94%.

Comparing both results, it should be emphasised that the reliability of the bread production process in the robotized part was improved by 6%. These tests indicate a measurable impact of robotization on the reliability calculated on the basis of probabilistic models in the bakery industry.

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