Analiza iskorišćenja kapaciteta u industrijskoj proizvodnji u funkciji racionalnog korišćenja resursa

Miroslav Radojičić¹, Jasmina Vesić-Vasović¹, Vladan Paunović¹, Zoran Nešić^{1*}

¹ Univerzitet u Kragujevcu, Fakultet tehničkih nauka u Čačku/Industrijski menadžment, Čačak (Srbija)

U radu je ukazano na neke mogućnosti integracije vremenskog i vrednosnog aspekta iskorišćenosti mašinskih kapaciteta, u okviru određenog proizvodnog procesa. Na razmatranom primeru pokazano je da se u konkretnim proizvodnim uslovima mogu bolje koristiti skuplje mašine u odnosu na jeftinije. Takođe je prikazano da treba dati pravi značaj realnom izračunavanju troškova amortizacije mašina i uticaju tih troškova na cenu koštanja proizvoda, a time i na konkurentnost preduzeća. Naglašeno je da se osim vremenskog stepena iskorišćenja kapaciteta mora dati poseban značaj i vrednosno-vremenskom stepenu korišćenja kapaciteta kojim se naglašava efikasna upotreba nedostajućih resursa u proizvodnji. Višekriterijumskim pristupom optimizaciji iskorišćenja proizvodnih kapaciteta stvaraju se mogućnosti da se adekvatnim izborom tehnološke koncepcije omogući racionalan pristup pri izboru načina eksploatacije mašina, posebno onih skupljih koji predstavljaju kapitalno intenzivni deo tehnološke opreme u proizvodnji.

Ključne reči: stepen iskorišćenosti proizvodnih kapaciteta, amortizacija, višekriterijumska analiza

1. UVOD

Mogućnosti određenog proizvodnog preduzeća da proizvede određenu količinu proizvoda, u velikoj meri zavisi od proizvodnog kapaciteta. Pojam kapaciteta, sa tačke gledišta proizvodnje, predstavlja sposobnost proizvodne kompanije da proizvede određenu količinu materijalnih dobara za određeni vremenski period [1].

Teorijska i praktična istraživanja pokazuju sve veća interesovanja za primenu različitih metoda i tehnika za rešavanje problema dužine trajanja proizvodnog ciklusa i optimizacije iskorišćenja proizvodnih kapaciteta [3] u funkciji unapređenja organizacije proizvodnih sistema [5], [6]. Analiza proizvodnih kapaciteta ima bitan uticaj na unapređenje njihovog iskorišćenja [7], [14]. Čala i ostali (2011) predlažu razvoj stohastičkog modela pri određivanju vremena ciklusa proizvodnje i njihove optimizacije [2]. Wang i ostali svoja istraživanja usmeravaju u pravcu modela planiranja proizvodnje u funkciji smanjenja rizika [8]. Neki od značajnih pravaca istraživanja u ovom području predstavljaju formiranje različitih modela proizvodnih sistema [15], [16].

U ovom radu je analiziran vrednosno-vremenski stepen iskorišćenja mašinskih kapaciteta u odnosu na stvarni stepen iskorišćenosti kapaciteta pri izradi složenog proizvoda, u okviru određenog proizvodnog procesa. Vrednosno-vremenski stepen iskorišćenja mašinskih kapaciteta omogućava analizu angažovanih osnovnih sredstava uzimajući u obzir, pored vrednosne dimenzije i stepen iskorišćenja njihove finansijske vrednosti. U tom smislu analiza iskorišćenja proizvodnih kapaciteta [19] se reflektuje na unapređenje operativnog planiranja proizvodnje [17], [18], odnosno efikasnijom proizvodnjom [20]. Prikazana analiza ima direktan i najznačajniji uticaj na ekonomske aspekte proizvodnog procesa [21]-[23] i optimizaciju proizvodnog procesa [24], [25].

Razmatrane su tehnološke i organizacione mogućnosti za bolje iskorišćenje kapaciteta na primeru preduzeća odbrambene industrije. Podaci koji su korišćeni za proračun stepena iskorišćenosti proizvodnih kapaciteta, kao i za proračun vrednosno-vremenskog stepena iskorišćenja dobijeni su kao rezultat snimanja pozicije P1 proizvodnog procesa složenog proizvoda koji ulazi u sastav proizvodnog programa Kompanije a.d. "Sloboda" Čačak. Proizvod se sastoji iz 9 podpozicija čija izrada zahteva realizaciju niza različitih operacija, različitog vremena trajanja, realizovanih na različitim mašinama.

Za izabrani proizvod je izvršena detaljna analiza tehnološkog postupka, korišćenih mašina i njihovih kapaciteta za seriju od 100000 komada. Proizvodni proces na poziciji P1, je predstavljen nizom proizvodnih operacija koje se izvode na 21 mašini. Na osnovu podataka o mašinskim kapacitetima za uslove rada u jednoj smeni (7.5h), dobijenih iz tehnoloških postupaka, izračunati su ukupni kapaciteti svake mašine za sve operacije koje se izvode u okviru pozicije P1.

2. ODREĐIVANJE STEPENA ISKORIŠĆENOSTI KAPACITETA ZA POZICIJU P1

Kapacitet mašine predstavlja određeno vreme za koje je neka mašina u stanju da izvrši određeni broj operacija. Svaki proces proizvodnje je uslovljen radnom sposobnošću mašina koje učestvuju u samom procesu, odnosno, mašinskim kapacitetima.

Pregled svih mašina koje se koriste u posmatranom proizvodnom procesu sa proračunatim raspoloživim kapacitetima dobijenim na osnovu trajanja proizvodnih operacija koje se na njima realizuju kao i stepen iskorišćenosti ovih mašina u odnosu na količinu proizvoda koju je neophodno proizvesti dat je u tabeli 1. U proizvodnji se koristi ukupno 21 mašina, različitog nivoa opterećenosti koji se kreće od 28% do 96%.

* Kontakt adresa autora: Fakultet tehničkih nauka u Čačku, Univerzitet u Kragujevcu, Svetog Save 65, 32000 Čačak, zoran.nesic@ftn.kg.ac.rs

Tabela 1: Iskorišćenost proizvodnih kapaciteta mašina

Rb.	Mašina (uređaj)	Iskorišćenost proizvodnih kapaciteta mašina [%]
1.	Presa hidraulična "Manurhin" 30t	32.00
2.	Okretnica pneumatska	60.00
3.	Mašina agregatna "Witzig Frank"	48.84
4.	Glodalica za navoj "Heller"	28.00
5.	Presa hidraulična "Hatrex"	76.00
6.	Strug doradni "Index"	60.00
7.	Strug doradni "Muller Montag"	88.00
8.	Mašina za lakovanje "Sprimag" $\Phi 800$	82.00
9.	Uređaj za tampon štampu	80.00
10.	Presa višestepena "Formmaster"	90.00
11.	Automat jednovretni "Schwerdtfeger"	90.00
12.	Aparat za odmašćivanje elemenata "Wacker"	80.00
13.	Mašina za samolikvidaciju	80.52
14.	Automat šestovretni "Gildemeister" AS-25	72.00
15.	Strug doradni "Auerbach"	40.00
16.	Mašina agregatna "SAS" - Bagat	96.00
17.	Glodalica stona	90.67
18.	Presa ručna	82.67
19.	Bušilica stona	90.58
20.	Glodalica horizontalna "Makers"	80.00
21.	Mašina za namotavanje opruga "Schenker"	88.00

Iz tabele 1, na osnovu izvršenih snimanja i dobijenih podataka o mesečnom kapacitetu svake mašine, izračunat je stepen iskorišćenosti kapaciteta za svaku mašinu za neophodnu količinu od 100000 komada. U okviru ovog proizvodnog procesa snimana je po jedna mašina različitog tipa. Takođe izračunat je stepen iskorišćenja kapaciteta cele grupe mašina koje učestvuju u ovom proizvodnom procesu i on iznosi 73,11%.

Na slici 1 je prikazan dijagram stepena iskorišćenosti proizvodnih kapaciteta za svaku od mašina, koje se koriste za izradu pozicije P1, u okviru razmatranog proizvodnog procesa, u zavisnosti od potrebne količine koja iznosi 100000 komada. Može se uočiti da je stepen iskorišćenosti pojedinih mašina značajno manji od 100%, tačnije kreće se u rasponu od 28% do 96%.

Slika 1: Stepene iskorišćenosti kapaciteta mašina

3. UTVRĐIVANJE AMORTIZACIJE MAŠINA ZA POZICIJU P1

Tokom svakog proizvodnog procesa koriste se određene mašine koje se vremenom troše, odnosno postepeno dolazi do smanjenja upotrebne vrednosti tih mašina, koja će nakon određenog vremena potpuno nestati.

Amortizacija mašina je vrednosna nadoknada za fizičko habanje i trošenje mašina, kao i njihovo zastarevanje u toku određenog procesa proizvodnje. Amortizacija mašina predstavlja postupak postepenog smanjenja vrednosti istih zbog njihovog reprodukcionog trošenja, kao i prenošenje odgovarajuće vrednosti u određivanje cene koštanja finalnog proizvoda.

Prilikom obračunavanja amortizacije mašina, ona se mora uskladiti sa stepenom njihove angažovanosti i iskorišćenosti, kao i sa obimom realizovane proizvodnje, odnosno sa količinom proizvoda. U ovom radu za izračunavanje godišnjeg iznosa amortizacije mašina korišćen je metod linearnog otpisa (2). Ovaj metod se najviše koristi u praksi, a zasniva se na tome da se mašine tokom svog perioda eksploatacije troše u jednakoj meri. Amortizacioni period predstavlja vreme u kome se početna vrednost mašine reprodukuje kako bi se za reprodukovani novčani iznos, na kraju amortizacionog perioda, nabavilo novo sredstvo [4]. Za određivanje godišnjeg iznosa amortizacije neophodno je znati nabavnu cenu mašine,

godine upotrebe mašine, kao i stopu amortizacije, svi podaci su prikazani u tabeli 2.

Stopa amortizacije se izračunava na osnovu sledeće relacije:

$$sA_m = \frac{(C_n - L_v)}{t \cdot C_n} \cdot 100\% \quad (1)$$

$$A_m = C_n \cdot sA_m \quad (2)$$

gde je:

C_n – nabavna cena i-te mašine

t – godine upotrebe i-te mašine

L_v – likvidaciona vrednost i-te mašine

sA_m – stopa amortizacije i-te mašine

A_m – godišnji iznos amortizacije i-te mašine

U tabeli 2 su prikazani podaci o nabavnoj ceni i godinama upotrebe za svaku mašinu koja se koristi u ovom proizvodnom procesu. Prikazane su i izračunate vrednosti stope amortizacije i godišnjeg iznosa amortizacije za svaku mašinu, primenom formule (1) i (2). Prilikom proračuna stope amortizacije za nove mašine pod rednim brojem 6 i 9, koje se koriste u prethodnih 5 godina, usvojeno je 10 godina kao planirani period eksploatacije.

Tabela 2: Prikaz izračunatih elemenata potrebnih za određivanje vrednosno-vremenskog stepena iskorišćenja kapaciteta

Rb.	Mašine (uređaji)	Cn [€]	t [god]	sAm [%]	Am [€]	η [%]	$\eta \cdot Am$
1.	Presa hidraulična "Manurhin" 30t	50000	35	2.86	1285.714	32.00	411.429
2.	Okretnica pneumatska	20000	15	6.67	1200.000	60.00	720.000
3.	Mašina agregatna "Witzig Frank"	15000	38	2.63	355.263	48.84	173.511
4.	Glodalica za navoj "Heller"	50000	15	6.67	3000.000	28.00	828.947
5.	Presa hidraulična "Hatrex"	20000	66	1.52	272.727	76.00	194.595
6.	Strug doradni "Index"	10000	5	10.00	900.000	60.00	1872.000
7.	Strug doradni "Muller Montag"	18000	63	1.59	257.143	88.00	840.000
8.	Mašina za lakovanje "Sprimag" $\Phi 800$	50000	27	3.70	1666.667	82.00	321.078
9.	Uređaj za tampon štampu	5000	5	10.00	450.000	80.00	207.273
10.	Presa višestepena "Formmaster"	700000	31	3.23	20322.581	90.00	540.000
11.	Automat jednovretni "Schwerdtfeger"	5000	78	1.28	57.692	90.00	226.286
12.	Aparat za odmašćivanje elemenata "Wacker"	30000	34	2.94	794.118	80.00	150.000
13.	Mašina za samolikvidaciju	9500	52	1.92	164.423	80.52	3459.375
14.	Automat šestovretni "Gildemeister" AS-25	110000	37	2.70	2675.676	72.00	1366.667
15.	Strug doradni "Auerbach"	10000	37	2.70	243.243	40.00	360.000
16.	Mašina agregatna "SAS" - Bagat	150000	37	2.70	3648.649	96.00	695.676
17.	Glodalica stona	8000	31	3.23	232.258	90.67	6428.571
18.	Presa ručna	5000	35	2.86	128.571	82.67	48600.000
19.	Bušilica stona	1000	29	3.45	31.034	90.58	49500.000
20.	Glodalica horizontalna "Makers"	40000	63	1.59	571.429	80.00	18290.323
21.	Mašina za namotavanje opruga "Schenker"	3000	37	2.70	72.973	88.00	51.923

4. UTVRĐIVANJE VREDNOSNO-VREMENSKOG STEPENA ISKORIŠĆENJA KAPACITETA

U ovom radu prikazan je takođe i stepen iskorišćenja finansijske vrednosti proizvodnih mašina, odnosno utvrđen je vrednosno-vremenski stepen korišćenja kapaciteta. Primenom vrednosno-vremenskog

stepena iskorišćenja kapaciteta mašina uspostavlja se zahtev za efikasnije korišćenje uložених finansijskih sredstava u proizvodne mašine, zatim za povećanje koeficijenta obrta, kao i sniženje cene koštanja finalnog proizvoda, odnosno postiže se efikasnija i delotvornija proizvodnja.

Izračunavanje vrednosno-vremenskog stepena iskorišćenja kapaciteta vrši se primenom sledeće relacije:

$$\eta_{vv} = \frac{\sum_{i=1}^j a_i \cdot \eta_i}{\sum_{i=1}^j a_i} \quad (3)$$

gde je:

η_i – vremenski stepen iskorišćenja i-te mašine

a_i – vrednost amortizacije i-te mašine

η_{vv} – vrednosno-vremenski stepen iskorišćenja kapaciteta

Primenom formule (3) izračunata je veličina vrednosno-vremenskog stepena iskorišćenja mašina za koju su potrebni podaci o vremenskom stepenu iskorišćenja mašina i vrednosti amortizacije tih mašina. Vrednost vrednosno-vremenskog stepena iskorišćenja mašina koje se koriste u razmatranom proizvodnom procesu iznosi 78,75%.

Na osnovu izračunatih vrednosti vremenskog stepena iskorišćenja kapaciteta koji iznosi 73,11% i vrednosno-vremenskog stepena iskorišćenja mašina koji iznosi 78,75%, može se zaključiti da je:

$$\eta_{vv} > \eta_i$$

dakle pokazano je da je u ovom proizvodnom procesu bolje korišćenje skupljih mašina u odnosu na jeftinije, tj. onih mašina koje imaju nisku amortizaciju.

5. PRIMENA METODE VIŠEKRITERIJUMSKOG ODLUČIVANJA U OPTIMIZACIJI KORIŠĆENJA PROIZVODNIH KAPACITETA

Višekriterijumska analiza problema iskorišćenosti kapaciteta mašina omogućava istovremeno razmatranje i vremenskog i vrednosnog aspekta korišćenja kapaciteta, kao i različitih vrsta prekida rada mašina, što daje sveobuhvatnu i jasniju sliku o razmatranom problemu.

Metode višekriterijumskog odlučivanja omogućavaju donosiocu odluke da rešava probleme uzimajući u obzir različite tačke gledišta, koje u pojedinim situacijama mogu biti kontradiktorne [9]. Veliki broj istraživanja je objavljen o primeni višekriterijumskih metoda [10], [13].

U zavisnosti od toga koje se metode koriste postoje različite načini i mogućnosti subjektivnog uticaja. PROMETHEE metoda [11], [12] uvodi nelinearnost preferencije i nudi više mogućnosti za izražavanjem subjektivnih preferenci odabirom tipa preferencijske funkcije i vrednosti parametara.

Sistem kriterijuma za višekriterijumsku analizu iskorišćenosti kapaciteta mašina je određen je sa ciljem da se istovremeno analizira i vremenski i vrednosni aspekt korišćenja kapaciteta, kao i različiti zastoji u radu mašina. U skladu sa tim definisani su kriterijumi pošto je na osnovu snimanja konstatovano da dolazi do prekida rada pojedinih mašina.

Rangiranje mašina je izvršeno primenom softvera Visual PROMETHEE u sistemu od 3 kriterijuma: stepen iskorišćenja kapaciteta mašina, vrednost amortizacije mašina i organizaciono-tehnološki zastoji (slika 2). Relativni značaj prva dva kriterijuma je isti i iznosi 0.4,

dok je za treći kriterijum usvojen relativni značaj 0.2. Svakom od kriterijuma je dodeljen Gausov tip preferencijske funkcije sa izračunatim vrednostima parametara σ .

Visual PROMETHEE Academic - IMK 14 sa raz ...			
File Edit Model Control PROMETHEE-GAIA GDSS GIS Custom			
Assistants Snapshots Options Help			
	Amortization...	The time deg...	Organization...
Unit	[€]	[%]	[h]
Cluster/Group	◆	◆	◆
Preferences			
Statistics			
Evaluations			
☒ Hydraulic presse...	1285,71	32,00	0,00
☒ Turning pneumatic	1200,00	60,00	437,00
☒ Aggregate machi...	355,26	48,84	1456,99
☒ Milling cutter for ...	3000,00	28,00	0,00
☒ Hydraulic presse...	272,73	76,00	1711,98
☒ Lathe finishing "I...	900,00	60,00	1570,98
☒ Lathe finishing "...	257,14	88,00	1729,98
☒ Machine for pain...	1666,67	82,00	1948,98
☒ The device for p...	450,00	80,00	1883,48
☒ Multistage press...	20322,58	90,00	167,00
☒ Single spindle au...	57,69	90,00	0,00
☒ Device for degre...	794,12	80,00	89,00
☒ Machine only liqu...	164,42	80,52	0,00
☒ Sixth spindles au...	2675,68	72,00	334,00
☒ Lathe finishing "...	243,24	40,00	0,00
☒ Aggregate machi...	3648,65	96,00	1122,99
☒ Milling cutter table	232,26	90,67	82,00
☒ Hand press	128,57	82,67	71,00

Actions: 21 (21 active) Criteria: 3 (3 active) Scenarios: 1 (1 active) Locale: ...

Slika 2: Višekriterijumska baza

Primenom softvera Visual PROMETHEE izvršeno je delimično rangiranje (slika 3).

Slika 3: Parcijalno rangiranje upoređivanih mašina

Višekriterijumskim rangiranjem upoređivanih alternativa (slika 4), mašina br. 19 - Bušilica ima bolju pozicioniranost u odnosu na ostale upoređivane mašine. Na drugom mestu se nalazi mašina br. 11 - Automat jednovretni "Schwerdtfeger", zatim mašina br. 21 - Mašina za namotavanje opruga "Schenker", itd.

Slika 4: Rangiranje pozicija upoređivanih mašina

GAIA ravan omogućava donosiocu odluke da dobije pouzdane informacije, kada je procenat informacija u GAIA ravni dovoljno velik, na primer veći od 80% (slika 5).

Slika 5: GAIA ravan

6. ZAKLJUČAK

Aktuelni momenat stanja i razvoja domaće privrede sve više ističe značaj racionalnog korišćenja nedostajućih rasursa, a to su finansijska sredstva potrebna za nabavku skupih tehnoloških mašina. U tom smislu treba povećati efikasnost korišćenja skupljih tehnoloških mašina u odnosu na jeftinije.

U radu je razmatran jedan model utvrđivanja uticajnih faktora na optimizaciju korišćenja proizvodnih kapaciteta. Pokazano je da treba dati pravi značaj realnom izračunavanju troškova amortizacije mašina i uticaju tih troškova na cenu koštanja proizvoda, a time i na konkurentnost preduzeća. Naglašeno je da se osim vremenskog stepena iskorišćenja kapaciteta mora dati poseban značaj i vrednosno-vremenskom stepenu korišćenja kapaciteta kojim se naglašava efikasna upotreba nedostajućih resursa u proizvodnji, a to su finansijska sredstva potrebna za ulaganje u proširenu reprodukciju. Na konkretnom primeru pokazano je kako se mogu bolje i efikasnije koristiti skuplje tehnološke mašine u odnosu na jeftinije. Ovo je samo jedan od elemenata kako se i kapitalno intenzivna proizvodnja, dobrom organizacijom i tehničkom pripremom, može učiniti ekonomski isplativa u našim uslovima i postojećem okruženju. Ovakav pristup omogućava analizu korišćenja proizvodnih kapaciteta u funkciji skraćenja proizvodnog ciklusa i sniženja troškova svedenih na jedinicu proizvoda.

ZAHVALNOST

Ovaj rad je rezultat istraživanja u okviru projekta TR35017 Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije.

LITERATURA

- [1] M. Božin, Radojičić M., "Organizacija i upravljanje", Univerzitet u Kragujevcu, Tehnički fakultet, Čačak (1997)
- [2] I. Cala, M. Klarin, M. Radojičić and Z. Erceg, "Development of a stochastic model for determining the elements of production cycle time and their optimization for serial production in metal processing industry and recycling processes," Plenary session-Invited papers, Proceedings of I International Symposium Engineering Management and Competitiveness-EMC2011, University of Novi Sad, Technical faculty Zrenjanin, pp. 21-24, (2011)
- [3] M. Klarin, D. D. Milanovic, M. Misita, V. Spasojevic-Brkic and A. Jovovic, "A method to assess capacity utilization layouts," Institution Of Mechanical Engineers Part E - Journal Of Process Mechanical Engineering, Vol. 224 (E1), pp. 49-58, (2010)
- [4] M. Radojičić, "Menadžment proizvodnjom", Univerzitet u Kragujevcu, Tehnički fakultet, Čačak, (2007)
- [5] L. Jingshan, S. M. Meerkov: "Production Systems Engineering", Springer, New York, USA, (2008)
- [6] J. Ch. Duncan: "The principles of industrial management", Fb & C Limited, London, (2015)
- [7] W. Abdul-Kader: "Capacity improvement of an unreliable production line-an analytical approach",

Computers and Operations Research, Vol. 33(6), pp. 1695-1712. (2006)

[8] Wang, X., Li, D., O'brien, C., & Li, Y. "A production planning model to reduce risk and improve operations management," International Journal of Production Economics, Vol. 124(2), pp. 463-474, (2010)

[9] P. Vincke, "Multicriteria Decision-Aid", John Wiley&Sons, New York, (USA) (1992)

[10] J. Figueira, S. Greco and M. Ehrgott,. "Multiple Criteria Decision Analysis: State of the Art Surveys," Springer Science&Business Media, Inc., (USA) (2005)

[11] J. P. Brans and P. Vincke, "A Preference Ranking Organization Method (The PROMETHEE Method for Multiple Criteria Decision-Making)," Management Science, Vol. 31(6), pp. 647-656, (1985)

[12] B. Mareschal, "Weight stability intervals in the PROMETHEE multicriteria decision - aid method," European Journal of Operational Research, Vol. 33, pp.54-64, (1988)

[13] J. Vesic Vasovic, M. Radojicic, M. Klarin, and V. Spasojevic-Brkic, "Multi-criteria approach to optimization of enterprise production programme," Proceedings of the Institution of Mechanical Engineers, Part B - Journal of Engineering Manufacture, Vol. 225 (10), pp. 1951-1963, (2011)

[14] D. S. Cochran, Y. S. Kim and J. Kim, "The impact of performance measurement on manufacturing system design," First International Conference on Axiomatic Design Cambridge, (2000)

[15] M. Rolón and E. Martínez, "Agent-based modeling and simulation of an autonomic manufacturing execution system," Computers in Industry, Vol. 63(1)., pp. 53-78, Elsevier Science Publishers B. V. Amsterdam, The Netherlands, (2012)

[16] S. H. Yoo, D. S. Kim and M. S. Park, "Inventory models for imperfect production and inspection processes with various inspection options under one-time and continuous improvement investment," Computers and Operations Research, Vol. 39(9), pp. 2001-2015, Elsevier Science Ltd. Oxford, UK, (2012)

[17] W. Stevenson, "Operations Management," McGraw-Hill/Irwin; 10 edition, (2008)

[18] R. B., Shase, F.R. Jacobs and N.J. Aguilano, "Operations Management For Competitive Advantage," McGraw-Hill/Irwin; 11th edition, New York, 2006.

[19] S. C. Ray, K. Mukherjee and Y. Wu, "Direct and Indirect Measures of Capacity Utilization: A Non-Parametric Analysis of US Manufacturing," Manchester School, Vol. 74(4), pp. 526-548, (2006)

[20] T. M. Wolf, "Production Capacity Versus Customer Demand," University of Wisconsin – Stout Menomonee, Wisconsin, (2011)

[21] S. Rasmussen, "Production Economics: The Basic Theory of Production Optimisation," Springer Science & Business Media, New York, (2012)

[22] B. R. Beattie, Ch. R. Taylor and M. J. Watts, "The Economics of Production," Krieger Pub., Malabar, Fla., (2009)

[23] S. T. Hackman, "Production Economics: Integrating the Microeconomic and Engineering Perspectives," Springer Science & Business Media, Berlin, (2008)

[24] S. Rasmussen, "Optimisation of Production Under Uncertainty: The State-Contingent Approach," Springer Science & Business Media, Berlin, (2011)

[25] R. V. Rao, "Advanced Modeling and Optimization of Manufacturing Processes: International Research and Development," Springer Science & Business Media, London, (2010)

An Analysis of Capacity Utilization in Industrial Production in Function of Rational Resource Use

Miroslav Radojicic¹, Jasmina Vesic-Vasovic¹, Vladan Paunovic¹, Zoran Nesic^{1*}

¹ University of Kragujevac, Faculty of Technical Sciences Čačak / Industrial management, Čačak (Serbia)

The paper indicates some possibilities of the integration of the temporal and value aspects of using machine capacities in the framework of a certain production process. The considered example has shown that in concrete production conditions more expensive machines are better used than cheaper ones. It has also shown that real significance should be given to the real calculation of the costs of the amortization of machines and the influence of those costs on the cost price of a product, and at the same time on the competitiveness of an enterprise. It is highlighted that apart from the temporal degree of capacity utilization, special significance should also be given to value-time degree of capacity utilization, which emphasizes the efficient use of the missing resources in production. A multicriteria approach to the optimization of production capacity utilization creates, by an adequate choice of a technological concept, possibilities for enabling a rational approach when choosing how to exploit machines, especially those more expensive, which are the capital intensive part of technological equipment in production.

Key words: degree of production capacity utilization, amortization, multicriteria analysis

1. INTRODUCTION

The possibilities of a certain production company to produce a certain amount of products depend to a large extent on the production capacity. From the point of view of production, the concept of capacity is the ability of a manufacturing company to produce a certain amount of material goods in a certain period of time [1].

Theoretical and experimental studies have shown an increasing interest in the use of different methods and techniques for solving the problem of the production cycle length and the optimization of the production capacity utilization [3] at improving the organization of production systems [5], [6]. The analysis of production capacities has a significant impact on improving their efficiency [7], [14]. Čala et al. (2011) proposed the development of a stochastic model for determining the cycle time of production and their optimization [2]. Wang and others directed their research towards the production planning model in the function of reducing the risk [8]. Some of the important research directions in this area represent the formation of different models of production systems [15], [16].

In this paper the value-time degree of the efficiency of machine capacity in relation to the actual level of the utilization of the complex product within a certain manufacturing process is discussed. The value-time efficiency of machine capacity enables the analysis of the involved fixed assets, additionally taking into account the value dimension and the efficiency of their financial use. In this sense, the analysis of the utilization of production capacity [19] is reflected in the improvement of the operational planning of production [17], [18] and more efficient production [20]. The presented analysis has a direct and significant impact on the economic aspects of the production process [21]-[23] and the optimization of the entire production process [24], [25].

The technological and organizational capabilities for better capacity utilization on the example of the

defense industry were considered. The data used for the calculation of the utilization degree of production capacity, as well as for the calculation of the value-time efficiency, were obtained as the result of the recording of the position P1 of the production process of a complex product, which became part of the production program of the company "Sloboda" Čačak. The product consists of 9 sub-positions, whose production requires the implementation of a number of different operations of different duration, realized on different machines.

For the selected product, a detailed analysis of the technological process, the used machines and their capacities for a series of 100,000 pieces was performed. The production process at Position P1 was presented through a series of manufacturing operations, performed on 21 machines. On the basis of the information on the machine capacity for the work conditions on one shift (7.5h), derived from the technological processes, the total capacity of each machine for all the operations performed within Position P1 was calculated.

2. THE CALCULATION OF THE CAPACITY UTILIZATION FOR POSITION P1

Machine capacity represents a certain amount of time in which a machine is able to perform a number of operations. Each production process is conditioned by the working capacity of the machines included in the process, i.e. by machine capacities.

The review of all the machines used in the observed production process, together with the calculated available capacities obtained on the basis of the duration of the manufacturing operations implemented on them, as well as the level of the utilization of these machines, compared to the amount of the product necessary to produce is given in Table 1. In the production, as many as 21 machines with different levels of the workload ranging from 28% to 96% were used.

*Corresponding author: Zoran Nešić: Faculty of Technical Sciences, Svetog Save 65, 32000 Čačak, Serbia, zoran.nesic@ftn.kg.ac.rs

Table 1: The utilization of the production capacity of the machines

No.	Machine (device)	Utilization of production capacity of machines [%]
1.	Hydraulic presses "Manurhin" 30t	32.00
2.	Pneumatic Switch	60.00
3.	Aggregate machine "Witzig Frank"	48.84
4.	Milling cutter for thread "Heller"	28.00
5.	Hydraulic presses "Hatrex"	76.00
6.	Lathe finishing "Index"	60.00
7.	Lathe finishing "Muller Montag"	88.00
8.	Machine for painting "Sprimag" $\Phi 800$	82.00
9.	The device for pad printing	80.00
10.	Multistage presses "Formmaster"	90.00
11.	Single spindle automat "Schwerdtfeger"	90.00
12.	Device for degreasing elements "Wacker"	80.00
13.	Machine for self-liquidation	80.52
14.	Sixth spindles automat "Gildemeister" AS-25	72.00
15.	Lathe finishing "Auerbach"	40.00
16.	Aggregate machine "SAS" - Bagat	96.00
17.	Milling cutter table	90.67
18.	Hand press	82.67
19.	Drill table	90.58
20.	Horizontal Milling cutter "Makers"	80.00
21.	Coil winding machine "Schenker"	88.00

From Table 1, based on the performed recordings and the obtained data on the monthly capacity of each machine, the degree of capacity utilization for each machine for the necessary quantity of 100,000 pieces was calculated. Within the production process, one of each type of the machines was used. The capacity utilization rate of the whole group of the machines engaged in the production process was also calculated and it is 73.11%.

Figure 1 is a diagram of the utilization degree of the production capacity for each of the machines used for creating Position P1 within the framework of the considered production process, depending on the required volume of 100,000 pieces. We noticed that the level of the utilization of the individual machines was significantly less than 100%, i.e. more specifically it ranges from 28% to 96%.

Figure 1: The degree of the utilization of machine capacities

3. THE DETERMINATION OF THE AMORTIZATION OF MACHINES FOR POSITION P1

During each production process, specific machines which eventually deteriorate are used; namely, there is a gradual decrease in the usage value of these machines, which completely disappears after a certain time.

The amortization of machines is the value of the compensation for the physical wear and tear of machines, and their obsolescence during the specific production process. The amortization of machines is the process of a gradual decrease in values because of their reproductive wear and tear, as well as the transfer of corresponding values in the determination of the cost of the final product.

During the computation of the amortization of machines, they must be synchronized with the degree of their involvement and utilization, as well as the volume of the realized production or the amount of products. For the calculation of the annual amount of the amortization of machines, the method of linear write-off (2) was used in this paper. This method is most frequently used in practice and bases on the fact that, during their operation period, machines wear out in an equal measure.

The amortization period is the time in which the initial value of a machine is reproduced, in order to acquire a new asset at the end of the amortization period for the reproduced amount of money [4]. For the purpose of determining the annual amount of amortization, it is necessary to know the purchase cost of the machine, the

years of the machine use, as well as the depreciation rate. All the data are presented in Table 2.

The depreciation rate is calculated based on the following relation:

$$sA_m = \frac{(C_n - L_v)}{t \cdot C_n} \cdot 100\% \quad (1)$$

$$A_m = C_n \cdot sA_m \quad (2)$$

where:

C_n – the purchase price of the i-th machine

t – the years of the use of the i-th machine

L_v – the liquidation value of the i-th machine

sA_m – the amortization rate of the i-th machine

A_m – the annual amount of the amortization of the i-th machine

Table 2 presents the data on the purchase price and the years of use for each machine used in the production process. Also, the calculated values of the depreciation rates and the annual amount of amortization for each machine are accounted for by applying Formulas (1) and (2). During the calculation of the amortization rates for new machines, under numbers 6 and 9, used in the past 5 years, the period of 10 years was adopted as the planned period of exploitation.

Table 2: The display of the calculated elements necessary for the determination of the value-time efficiency capacity

No.	Machine (device)	C _n [€]	t [years]	sA _m [%]	A _m [€]	η [%]	η·A _m
1.	Hydraulic presses "Manurhin" 30t	50000	35	2.86	1285,714	32.00	411,429
2.	Pneumatic Switch	20000	15	6.67	1200,000	60.00	720,000
3.	Aggregate machine "Witzig Frank"	15000	38	2.63	355,263	48.84	173,511
4.	Milling cutter for thread "Heller"	50000	15	6.67	3000,000	28.00	828,947
5.	Hydraulic presses "Hatrex"	20000	66	1.52	272,727	76.00	194,595
6.	Lathe finishing "Index"	10000	5	10.00	900,000	60.00	1872,000
7.	Lathe finishing "Muller Montag"	18000	63	1.59	257,143	88.00	840,000
8.	Machine for painting "Sprimag" Φ800	50000	27	3.70	1666,667	82.00	321,078
9.	The device for pad printing	5000	5	10.00	450,000	80.00	207,273
10.	Multistage presses "Formmaster"	700000	31	3.23	20322,581	90.00	540,000
11.	Single spindle automat "Schwerdtfeger"	5000	78	1.28	57,692	90.00	226,286
12.	Device for degreasing elements "Wacker"	30000	34	2.94	794,118	80.00	150,000
13.	Machine for self-liquidation	9500	52	1.92	164,423	80.52	3459,375
14.	Sixth spindles automat "Gildemeister" AS-25	110000	37	2.70	2675,676	72.00	1366,667
15.	Lathe finishing "Auerbach"	10000	37	2.70	243,243	40.00	360,000
16.	Aggregate machine "SAS" - Bagat	150000	37	2.70	3648,649	96.00	695,676
17.	Milling cutter table	8000	31	3.23	232,258	90.67	6428,571
18.	Hand press	5000	35	2.86	128,571	82.67	48600,000
19.	Drill table	1000	29	3.45	31,034	90.58	49500,000
20.	Horizontal Milling cutter "Makers"	40000	63	1.59	571,429	80.00	18290,323
21.	Coil winding machine "Schenker"	3000	37	2.70	72,973	88.00	51,923

4. The Determination of the Value-Time Degree of Capacity Utilization

In this paper, the degree of the efficiency of the financial values of production machines is also presented; namely, the value-time degree of capacity utilization is established. The application of the value-time efficiency rate of machines means a more efficient use of the

financial resources invested in production machines and an increase in the coefficient of trades, as well as the lowering of the cost of the final product, thus achieving more efficient and more effective production.

The calculation of value-time degree of capacity utilization is carried out using the following relation:

$$\eta_{vv} = \frac{\sum_{i=1}^j a_i \cdot \eta_i}{\sum_{i=1}^j a_i} \quad (3)$$

where:

η_i – the time degree of the efficiency of the i -th machine

a_i – the amortization of the i -th machine

η_{vv} – the value-time degree of capacity utilization

By applying Formula (3), the magnitude of the value-time degree of the utilization of machines is calculated, requiring data on the degree of the time degree of the utilization of machines and the values of the amortization of these machines. The value of the value-time degree of the utilization of machines used in the production process is 78.75%.

Based on the calculated value of the time degree of capacity utilization, which is 73.11%, and the value-time degree of the efficiency of machines, which is 78.75%, it can be concluded that:

$$\eta_{vv} > \eta_i$$

Therefore, the above shows that, in this production process, it is better to use more expensive machines than those cheaper, i.e. it is better to use machines characterized by low amortization.

5. THE APPLICATION OF MULTIPLE CRITERIA METHODS IN THE OPTIMIZATION OF PRODUCTION CAPACITY

The multicriteria analysis of the problem of the capacity utilization of machines enables the simultaneous consideration of the time and the value aspects of capacity utilization, as well as different types of machine downtime, which gives a comprehensive and clear picture of this problem. Methods for decision making allow decision makers to solve problems, taking into account different points of view, which in some situations may be contradictory [9]. A large number of studies have been published on the application of the multicriteria method [10], [13].

Depending on the methods used, there are different ways and possibilities of a subjective influence. The PROMETHEE method [11], [12] introduces the non-linearity of preferences and offers more opportunities for the expression of subjective preferences by selecting preferential functions and parameter values. The system of criteria for a multiple-criteria analysis of the capacity utilization of machines is determined in order to simultaneously analyze both the time aspect and the value aspect of capacity utilization, as well as various machine downtimes. Accordingly, the criteria are defined, since on the basis of the recording it was concluded that certain machines were in their downtime. The ranking of machines is performed using the Visual PROMETHEE software in the system of the three criteria: the degree of the capacity utilization of machines, the value of the amortization of machines, organizational and technological delays (Figure 2). The relative importance of the first two criteria is the same and amounts to 0.4, whereas for the third criterion, the adopted relative

importance is 0.2. Each criterion is assigned a preferential Gaussian function with the calculated values of the parameters σ .

Scenario1	Amortization...	The time deg...	Organization...
Unit	[€]	[%]	[h]
Cluster/Group	◆	◆	◆
Preferences			
Statistics			
Evaluations			
Hydraulic presse...	1285,71	32,00	0,00
Turning pneumatic	1200,00	60,00	437,00
Aggregate machi...	355,26	48,84	1456,99
Milling cutter for ...	3000,00	28,00	0,00
Hydraulic presse...	272,73	76,00	1711,98
Lathe finishing "I...	900,00	60,00	1570,98
Lathe finishing "...	257,14	88,00	1729,98
Machine for pain...	1666,67	82,00	1948,98
The device for p...	450,00	80,00	1883,48
Multistage press...	20322,58	90,00	167,00
Single spindle au...	57,69	90,00	0,00
Device for degre...	794,12	80,00	89,00
Machine only liqu...	164,42	80,52	0,00
Sixth spindles au...	2675,68	72,00	334,00
Lathe finishing "...	243,24	40,00	0,00
Aggregate machi...	3648,65	96,00	1122,99
Milling cutter table	232,26	90,67	82,00
Hand press	128,57	82,67	71,00

Figure 2: A multicriteria database

The partial ranking was performed by using the Visual PROMETHEE software (Figure 3).

Figure 3: The partial ranking of the compared machines

By the multicriteria ranking of the alternatives compared (Figure 4), machine no. 19 – Drill has better positioning in relation to the other machines compared. Machine no. 11 - Single spindle Automat “Schwerdtfeger” is ranked the second, Machine no. 21 - Machine for winding spring “Schenker” is ranked the third and so forth.

Figure 4: The ranking of the position of the compared machines

The GAIA level allows decision makers to obtain reliable information, when the percentage of information at the GAIA level is large enough, for example, greater than 80% (Figure 5).

Figure 5: GAIA level

6. CONCLUSION

The current moment of the state and development of the national economy has increasingly been emphasizing the importance of the rational use of insufficient resource allocation, namely the funds required for the purchase of expensive technological machines. In this context, it is necessary to increase the efficiency of using expensive technological machines in comparison with cheaper ones.

In the paper, a model of determining the factors of the influence on the optimization of the use of production capacity is considered. It is demonstrated that true significance should be given to the realistic calculation of the costs of the amortization of machines and the impact of these costs on the cost of the product, and thus on the competitiveness of enterprises. It is stressed that, in addition to the time degree of capacity utilization, special importance must also be given to the value-time level of capacity utilization, which emphasizes the efficient use of the missing resources in production, namely financial resources needed to invest in expanded reproduction. On the concrete example, it is shown how more expensive technological machines can be used better and more efficiently in comparison with other cheaper ones. This is merely one of the elements showing how capital-intensive production can be made economically feasible in our conditions and the existing environment by applying good organization and technical preparation. This approach enables the analysis of the utilization of production capacities in the function of shortening the production cycle and lowering costs reduced to the unit of production.

ACKNOWLEDGEMENTS

This paper is the result of research within Project TR35017 of the Ministry of Education, Science and Technological Development of the Republic of Serbia.

REFERENCES

- [1] M. Božin, Radojičić M., “Organizacija i upravljanje”, University of Kragujevac, Technical Faculty, Čačak (1997).
- [2] I. Čala, M. Klarin, M. Radojičić and Z. Erceg, “Development of a stochastic model for determining the elements of production cycle time and their optimization for serial production in metal processing industry and recycling processes,” Plenary session-Invited papers, Proceedings of I International Symposium Engineering Management and Competitiveness-EMC2011, University of Novi Sad, Technical faculty Zrenjanin, pp. 21-24, (2011)
- [3] M. Klarin, D. D. Milanovic, M. Misita, V. Spasojevic-Brkic and A. Jovovic, “A method to assess capacity utilization layouts,” Institution Of Mechanical Engineers Part E - Journal Of Process Mechanical Engineering, Vol. 224 (E1), pp. 49-58, (2010)
- [4] M. Radojičić, “Menadžment proizvodnjom”, University of Kragujevac, Technical Faculty, Čačak, (2007)
- [5] L. Jingshan, S. M. Meerkov: "Production Systems Engineering", Springer, New York, USA, (2008)

- [6] J. Ch. Duncan: "The principles of industrial management", Fb & C Limited, London, (2015)
- [7] W. Abdul-Kader: "Capacity improvement of an unreliable production line-an analytical approach", Computers and Operations Research, Vol. 33(6), pp. 1695-1712. (2006)
- [8] Wang, X., Li, D., O'Brien, C., & Li, Y. "A production planning model to reduce risk and improve operations management," International Journal of Production Economics, Vol. 124(2), pp. 463-474, (2010)
- [9] P. Vincke, "Multicriteria Decision-Aid", John Wiley & Sons, New York, (USA) (1992)
- [10] J. Figueira, S. Greco and M. Ehrgott, "Multiple Criteria Decision Analysis: State of the Art Surveys," Springer Science & Business Media, Inc., (USA) (2005)
- [11] J. P. Brans and P. Vincke, "A Preference Ranking Organization Method (The PROMETHEE Method for Multiple Criteria Decision-Making)," Management Science, Vol. 31(6), pp. 647-656, (1985)
- [12] B. Mareschal, "Weight stability intervals in the PROMETHEE multicriteria decision - aid method," European Journal of Operational Research, Vol. 33, pp. 54-64, (1988)
- [13] J. Vesic Vasovic, M. Radojicic, M. Klarin, and V. Spasojevic-Brkic, "Multi-criteria approach to optimization of enterprise production programme," Proceedings of the Institution of Mechanical Engineers, Part B - Journal of Engineering Manufacture, Vol. 225 (10), pp. 1951-1963, (2011)
- [14] D. S. Cochran, Y. S. Kim and J. Kim, "The impact of performance measurement on manufacturing system design," First International Conference on Axiomatic Design Cambridge, (2000)
- [15] M. Rolón and E. Martínez, "Agent-based modeling and simulation of an autonomic manufacturing execution system," Computers in Industry, Vol. 63(1), pp. 53-78, Elsevier Science Publishers B. V. Amsterdam, The Netherlands, (2012)
- [16] S. H. Yoo, D. S. Kim and M. S. Park, "Inventory models for imperfect production and inspection processes with various inspection options under one-time and continuous improvement investment," Computers and Operations Research, Vol. 39(9), pp. 2001-2015, Elsevier Science Ltd. Oxford, UK, (2012)
- [17] W. Stevenson, "Operations Management," McGraw-Hill/Irwin; 10 edition, (2008)
- [18] R. B., Shase, F.R. Jacobs and N.J. Aguilano, "Operations Management For Competitive Advantage," McGraw-Hill/Irwin; 11th edition, New York, 2006.
- [19] S. C. Ray, K. Mukherjee and Y. Wu, "Direct and Indirect Measures of Capacity Utilization: A Non-Parametric Analysis of US Manufacturing," Manchester School, Vol. 74(4), pp. 526-548, (2006)
- [20] T. M. Wolf, "Production Capacity Versus Customer Demand," University of Wisconsin – Stout Menomonie, Wisconsin, (2011)
- [21] S. Rasmussen, "Production Economics: The Basic Theory of Production Optimisation," Springer Science & Business Media, New York, (2012)
- [22] B. R. Beattie, Ch. R. Taylor and M. J. Watts, "The Economics of Production," Krieger Pub., Malabar, Fla., (2009)
- [23] S. T. Hackman, "Production Economics: Integrating the Microeconomic and Engineering Perspectives," Springer Science & Business Media, Berlin, (2008)
- [24] S. Rasmussen, "Optimisation of Production Under Uncertainty: The State-Contingent Approach," Springer Science & Business Media, Berlin, (2011)
- [25] R. V. Rao, "Advanced Modeling and Optimization of Manufacturing Processes: International Research and Development," Springer Science & Business Media, London, (2010)