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# Analiza radnog ciklusa na primeru viljuškara

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*U radu je prikazana nova metodologija za analizu rada jednopozicionih transportnih mašina (uređaja). Metodologija daje teorijske osnove za razvoj novih metoda za preciznije određivanje ponašanja prosečnog radnog ciklusa kao i metoda za analizu parametara tehnološke funkcije transportnih mašina (uređaja). Analiza radnog ciklusa viljuškara je korišćena kao primer primene prikazane metodologije. Funkcije raspodele vremena trajanja radnog ciklusa viljuškara su određene na osnovu najznačajnijih parametra koji utiču na rad istog.*

**Ključne reči: sistemski pristup, metodologija, radni ciklus, viljuškar**

## 0. UVOD

Uobičajeno je, posebno u inženjerskim krugovima, da se pod terminom "projektovanje" podrazumeva kreacija (novih) fizičkih sistema - hardvera. Međutim, projektovanje kao aktivnost uopšte, odnosi se, kako na kreaciju fizičkih proizvoda (bilo koje vrste - u tom okviru posebno tehničkih, ili prvo tehničkih, ako je o inženjerima reč), tako u istoj meri, objekti - predmeti projektovanja su procesi, procedure, metode i organizacije, tj. softveri - softsistemi.

U projektovanju predmeta - objekata tako raznolikih oblasti, koriste se, isto tako, brojne metodologije i opšti i posebni metodi analize, sinteze, evaluacije i optimizacije različitih osobina - atributa sistema i njihovih delova (elemenata).

Klasične metode su davale očekivane rezultate (efekte) - koji su se sredstvima i znanjima kojima se raspolagalo, mogli dobiti kao najbolji.

Sve stvari se menjaju i razvijaju se novi, recimo, matematički aparati i alati, pa se shodno tome mogu unapređivati i metode koje te vrste aparata koriste.

Razvoj novih znanja i sve većih mogućnosti računarske tehnologije, novi prilazi u rešavanju problema i odgovarajući razvoj novih metoda, obezbeđuju da se znatno povećavaju mogućnosti dolaženja do optimalnih rešenja i time povećaju efekti aktivnosti projektovanja (složenih) sistema.

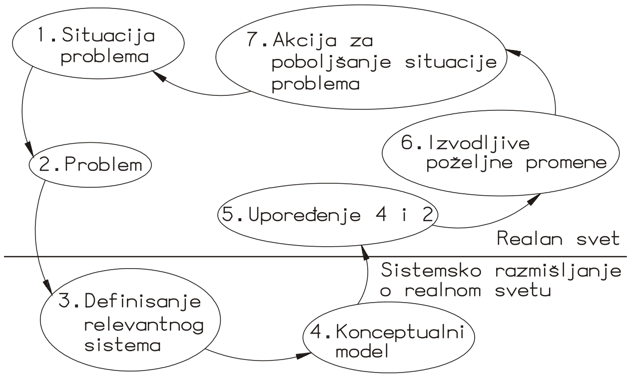
Međutim, projektovanje kao aktivnost i disciplina, otvara mnoga polja širokih programa i posebnih projekata istraživanja i traženja rešenja za nove prilaze i metode u projektovanju.

Razvoj nove metode uvek proističe iz potrebe da se poboljšaju mogućnosti dobijanja pravih rešenja za probleme koji su predmet projektovanja, s jedne strane, kao i iz sagledavanja mogućnosti koje daju nepotpuno iskorišćeni alati odnosno matematički modeli koji su razvijeni za obradu - rešavanje problema stohastičke prirode.

Ako su razvijene metodologije i posebni metodi uspešno primenjeni u jednoj oblasti rešavanja projektnih zadataka, ne znači da su oni i opšte primenljivi za rešavanje drugih i drugačijih zadataka. Nema opšte važećih, univerzalnih metodologija i metoda. To ukazuje na probleme izbora odgovarajuće metodologije, odnosno metoda za rešavanje svakog konkretnog projektnog zadatka i/ili njegovog dela, kao i pojavu potreba istraživanja, razvoja i projektovanja boljih. [6]

Checkland uopštava ideju o sistemskom prilazu (metodologiji) od realizacije industrijskih sistema ("hard systems") kod kojih se mogu ciljevi relativno lako definisati, jasno definisati procedure donošenja odluka i kvantitativno meriti performanse, prema realizaciji tzv. "soft systems" (rešavanju problema realnog sveta) kod kojih je ciljeve teško definisati, gde su procedure za donošenje odluka nesigurne dok je vrednovanje performansi u najboljem slučaju kvalitativno (npr. menadžment, marketing, izdavaštvo itd.). [5]

Razvijena metodologija rešavanja problema realnog sveta sastoji se u sledećem: (slika 1) [2],[4]




*Sl. 1: Metodologija rešavanja problema realnog sveta*

## 1. RAZVOJ METODA ANALIZE I OPTIMIZACIJE VREMENA RADNOG CIKLUSA

S obzirom na pristupe i načine - metode koji se koriste u današnjoj praksi projektovanja tehničkih sistema, u ovom radu napor se usmerava na potrebu poboljšanja metoda analize i optimizacije parametara performansi (tehnološke funkcije) sistema. Iz tog okvira, predmet proučavanja i razvoja novog metoda je, između ostalog, vreme radnog ciklusa kao jednog od glavnih parametara performansi klase radnih mašina, označenih kao jednopozicione mašine, sa prekidnim načinom rada.

Objašnjenje problema i ciljeva ovog rada, daje se na primeru konkretnog tehničkog sistema - projektovanja i konstruisanja transportnih sistema određene klase.

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Pri projektovanju transportnih sistema, mogu se dogoditi dva karakteristična slučaja uzimajući u obzir vreme trajanja radnog ciklusa:

1. Ulaz u izbor i dimenzionisanje (faze planiranja i preliminarnog projektovanja sistema), sa komotnim - većim računskim vremenom radnog ciklusa, ima za posledice:
   - veće investicije u opremu (transportne mašine); dobija se veći broj mašina ili mašina većeg kapaciteta (teža, snažnija mašina, itd.),
   - povećan broj rukovalaca i radnika na transportu,
   - manji stepen korišćenja mašina i rada.
2. Ulaz u izbor i dimenzionisanje sistema sa tesnim - manjim računskim vremenom radnog ciklusa (od onog koji se može pojaviti u konkretnom slučaju realizacije procesa), za posledicu može imati:
   - podcenjeno potrebno ulaganje u potrebnu opremu (transportne mašine),
   - formiranje uskih grla,
   - teškoće u planiranju korišćenja sistema, potreba za naknadnim (do)investiranjem,
   - produžavanje ukupnog vremena proizvodnog ciklusa, zbog zastoja u procesu, gubitaka vremena zbog čekanja na pojedine operacije itd.

Performanse mašine - radni kapacitet, radna sposobnost sistema - transportne mašine, u (za)datom vremenu i uslovima rada zavise od veličine transportne jedinice i vremena trajanja radnog ciklusa. Prema izabranoj transportnoj jedinici određuje se nosivost uređaja (mašine), dok se prema položajima tačaka uzimanja materijala (pojedinih transportnih jedinica) i mestima odlaganja tog materijala, definišu operacije radnih ciklusa.

Za različite tačke odlaganja materijala u odnosu na jednu tačku (ili više različitih tačaka) uzimanja materijala, putanje premeštanja materijala su različite dužine, a i različitog su oblika. Ovde se radi, znači o skupu radnih ciklusa različitog trajanja, koji se u određenom periodu rada - času, smeni, mesecu itd., ređaju po nekom slučajnom zakonu promene. Po ovome rad mašine je stohastičke prirode. U zavisnosti od ukupnog transportnog zadatka za određeni period vremena, ukupna količina materijala koju treba premestiti sa polaznih tačaka na zadata mesta odlaganja (dotura) i kapacitet (radna moć) jedne mašine određuju broj potrebnih mašina.

Organizacija izvođenja pojedinih radnih ciklusa i izabrane brzine premeštanja materijala, odnosno izvršavanja pojedinih operacija, određuju vremena tih radnih ciklusa. Tačnije izračunavanje trajanja radnih ciklusa omogućuje pouzdaniji izbor teretnih jedinica, nosivosti i broja potrebnih mašina za zadati transportni zadatak. [2]

## 2. DEFINICIJA RADNOG CIKLUSA

U narednom tekstu biće definisan radni ciklus za tzv. jednopozicione mašine sa prekidnim načinom rada. Jednopozicione mašine su takve mašine kod kojih jednovremeno obrađuje samo jedan deo - proizvod i on je sve vreme na mašini. [1]

U radu svake mašine pojavljuju se međusobno povezane operacije različitog karaktera:

- operacije postavljanja materijala (predmeta rada, proizvoda, dela) na mašinu,
- operacije obrade (osnovne tehnološke),
- transportne operacije (premeštanja materijala i ljudi, definisanje putanja i brzina premeštanja),
- skidanje materijala sa mašine,
- kontrole,
- zamene alata,
- zahtevi i ograničenja za moguća preklapanja kretanja,
- spoljašnji i unutrašnji gubitci vremena,
- regulacije, itd.

Zbirno trajanje svih operacija tehnološkog procesa - kako osnovnih, tako i pomoćnih, koje nisu međusobno preklopljene po vremenu izvršavanja, karakteriše neophodno vreme za izvršenje tehnološkog procesa i zove se **Tehnološki ciklus mašine**-$T_t$. Nezavisno od toga, u nizu slučajeva, moguće je utvrditi drugi važan interval vremena $T_r$, taj interval deli momente izlaska sa mašine dva uzastopno obrađena dela (proizvoda) i naziva se **Radni ciklus mašine** (mašine ili sistema uopšte). On predstavlja interval vremena, neophodan za izlazak sa mašine jednog dela - jednog proizvoda.

Ako se na mašini jednovremeno obrađuje samo jedan deo - proizvod, onda je vreme tehnološkog ciklusa jednako vremenu radnog ciklusa: $T_t = T_r$.

Radi kompletiranja definicija ove vrste, navodi se još jedan važan interval vremena u radu svake mašine, a to predstavlja vreme potrebno za ponavljanje položaja svi članova radnog mehanizma mašine. Taj interval se naziva **Kinematski ciklus**.

Operacije tehnološkog ciklusa mogu se obavljati: postupno (jedna za drugom); paralelno (sve operacije u isto vreme) i paralelno-postupno (određeni broj operacija se obavlja postupno, a određeni paralelno.)

U zavisnosti od gore iznetog, vreme tehnološkog, odnosno radnog ciklusa, prikazano na primeru transportnih mašina, je:

- za mašine kod kojih se predmet rada sve vreme obrade nalazi u jednom položaju-poziciji i dok se obrada jednog dela ne završi nije moguće na mašinu postaviti drugi deo:

  $$T_t = T_r = t_{ps} + \Sigma t_r - \Sigma t_{pr} + \Sigma t_g,$$

  gde je:

  $t_{ps}$ - vreme postavljanja i skidanja dela,

  $\Sigma t_r$ - trajanje pomeranja radnog mehanizma (vreme izvršenja pojedinih radnih operacija),

  $\Sigma t_{pr}$ - vremena preklapanja izvođenja pojedinih operacija,

  $\Sigma t_g$ - vremena unutrašnjih i spoljašnjih gubitaka.
- za mašine kod kojih se sve operacije izvršavaju paralelno, tada je vreme tehnološkog, odnosno radnog ciklusa jednako:

  $$T_t = T_r = t_{ps} + t_{rmax} + \Sigma t_g.$$
- za mašine kod kojih se operacije izvršavaju paralelno-postupno, vremena tehnološkog, odnosno radnog ciklusa se određuju kao zbir dva vremena - za postupno izvršene operacije i za paralelno izvršene operacije.

U slučajevima rada mašina kada se stalno ponavljaju isti tehnološki, odnosno radni procesi, analiza i optimizacija vremena radnog ciklusa koji opredeljuje ukupni kapacitet - radnu moć mašine (funkcionalne performanse), nije veliki problem.

Problem nastaje kada su pojedini radni ciklusi različiti i ređaju se po nekom slučajnom zakonu, kako po predmetu rada (obrade, transporta i dr.), tako i po vremenu tehnološkog, odnosno radnog ciklusa za transportne operacije - po mestima uzimanja i po mestima odlaganja materijala.

Ovde se nailazi na problem definicije srednjeg vremena radnog ciklusa i zadatak razvoja metoda proračunavanja trajanja radnih ciklusa za složene stohastičke transportne zadatke, sa kojima se projektant redovno susreće u rešavanju problema izbora i dimenzionisanja transportnih, a uopšteno i svih drugih radnih mašina prekidnog načina rada. U ovom slučaju potrebno je razviti posebne (računarske) procedure, bazirane na stohastičkim modelima, za određivanje srednjeg vremena trajanja optimizovanog radnog ciklusa transportnog uređaja.

Radni ciklus tzv. jednopozicionih mašina uopšte, ima specifične karakteristike koje su naročito izražene kod transportnih mašina (uređaja) koji pripadaju ovoj klasi. Specifičnost se ogleda u tome što uvek postoji tačno određen minimalni (maksimalni) radni ciklus u zavisnosti od vremena trajanja. Ovo se može objasniti činjenicom da se radni ciklus jednopozicionih transportnih mašina sastoji iz niza operacija koje se moraju izvršiti pri svakom radnom ciklusu bez obzira na pomeranje samog transportnog uređaja.

## 3. ODREĐIVANJE PERFORMANSI - RADNE SPOSOBNOSTI SISTEMA

Uključivanje procedure definisanja parametara radnih ciklusa, uvođenjem razvijenih metoda analize i optimizacije, u algoritam određivanja parametara tehnološke funkcije - radne sposobnosti mašina (uređaja, sistema) sa prekidnim načinom rada (jednopozicione tehnološke, transportne i druge mašine) podrazumeva posmatranje rada datog uređaja u odgovarajućim - kritičnim vremenskim intervalima. Kritičnim u smislu da su oni merodavni za dimenzionisanje datog uređaja (sistema).

Jedan od važnih faktora koji utiče na određivanje parametara tehnološke funkcije jeste i stanje datog uređaja (sistema) na početku posmatranog kritičnog intervala. Početno stanje dovodi do nestacionarnog režima rada sistema. Trajanje nestacionarnog režima rada sistema zavisi od početnih uslova i u opštem slučaju ne zavisi od vremena trajanja posmatranog kritičnog intervala tj. nestacionarni režim rada sistema može biti ili duži ili kraći od vremena trajanja posmatranog kritičnog intervala. Ovo praktično znači da sistem može u toku trajanja celog kritičnog intervala da radi u nestacionarnom režimu ili da jedan deo vremena radi u nestacionarnom režimu a jedan deo u stacionarnom režimu rada što utiče na parametre tehnološke funkcije - radnu sposobnost. Parametri tehnološke funkcije - radna sposobnost datog sistema (uređaja) u nestacionarnom režimu rada zavise od vremena dok to nije slučaj u stacionarnom režimu rada.

U svrhu određivanja parametara tehnološke funkcije - radne sposobnosti sistema (uređaja) mogu se koristiti npr. odgovarajući modeli teorije redova kao i računarski programi za simulaciju rada datog sistema tj. uređaja.

## 4. KRETANJA MATERIJALA - ANALIZA RADNOG CIKLUSA VILJUŠKARA

Sistem unutrašnjeg transporta predstavlja rešenje problema kretanja materijala za određeni projektni zadatak. On obično rezultira kao integralni niz operacija, aktivnosti i toka informacija, tesno povezanih u cilju izvršavanja funkcije na način koji je izvodljiv i ekonomski opravdan.

Da bi ovakvi sistemi mogli da rade bez zastoja oni moraju da imaju odgovarajući kapacitet. Odstupanje od optimalnog kapaciteta dovodi do neefikasnog iskorišćenja opreme (više uređaja nego što je potrebno) ili do stvaranja velikih redova (manje uređaja nego što je potrebno), odnosno nagomilavanja materijala u pojedinim fazama procesa. Zadatak projektanta je da pravilno postavi sistem kretanja materijala da bi zadovoljio traženi kapacitet. U tu svrhu koriste se odgovarajući modeli procesa koji omogućuju nalaženje takve strukture transportnog sistema da se zadovolje uslovi postavljeni transportnim zadatkom. [3]

Potrebno je raspolagati nizom podataka o samom procesu da bi mogli da se koriste matematički modeli. Za primenu determinističkih modela potrebno je poznavati sve ulazne veličine i njihove zavisnosti, dok je za primenu stohastičkih modela potrebno poznavati raspodele relevantnih vremenskih parametara (karakter promene). Do raspodela vremenskih parametara moguće je doći snimanjem istih na sistemima koji su u eksploataciji. [7]

Za projektanta koji radi na formiranju novog sistema poznavanje podataka o raspodelama relevantnih parametara sličnih sistema je značajno jer na bazi njih on može da korišćenjem odgovarajućih modela predvidi ponašanje novo projektovanog sistema. Primenom odgovarajućih raspodela mogu se dobiti osnovni pokazatelji o radu novog sistema u željenim situacijama.

Poznavanje ovih parametara omogućuje korišćenje poznatih stohastičkih modela. Najviše korišćeni modeli u oblasti kretanja materijala su modeli masovnog opsluživanja. Oni su posebno pogodni za proučavanje sistema opsluživanja npr. unutrašnji transport skladištenje itd. Pored ovih modela koristi se i metoda simulacije za analizu transportnih tokova. Simulacija sistema kretanja materijala omogućava da se detaljno ispituju pojedini elementi transportnog sistema ali i ceo transportni sistem.

Prednost postupka simulacije u odnosu na analitičke modele je da često daje tačnije rezultate i nije potrebna skupa i dugotrajna provera rezultata dobijenih u eksploatacionim uslovima.

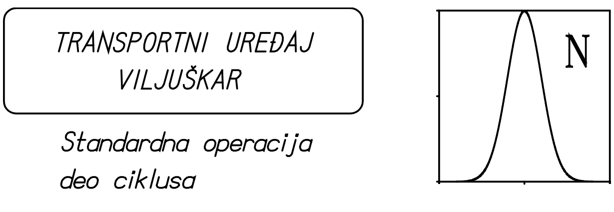
Problem projektovanja sistema kretanja materijala uslovljen je poznavanjem zahteva proizvodnje i specifičnih uslova eksploatacije. Pošto je svaki proizvodni sistem u okviru kojeg se nalazi i transportni sistem, problem za sebe, to se za ocenu ponašanja projektovanog sistema mogu koristiti samo podaci o sličnim izvedenim sistemima, tako da je opravdano analizirati postojeće sisteme, ustanoviti zavisnosti pojedinih klasa sistema, primenjenih uređaja, odnosno poznavati odgovarajuće parametre tehnološke funkcije. Pomoću ovih parametara tehnološke funkcije dolazi se do prosečnog ponašanja sistema koji se posmatra.

Analizu kretanja materijala treba početi od analize vremenskih parametara rada jer se njihovim poznavanjem mogu definisati aktivnosti transportnog sistema. Vremenski parametri koji su značaji za rad ovog podsistema su: vreme trajanja prosečnog ciklusa rada sa definisanjem odstupanja i stepena neravnomernosti, broj ciklusa koji se realizuje sa definisanjem vršnog broja u jedinici vremena, vremenski parametri povezivanja više uređaja u podsistem transporta (vreme čekanja na mestu pretovara i sl), vreme potrebno da se ostvari transportni zadatak i zbog toga potreban broj uređaja koji treba da rade, verovatnoća da se sistem nađe u određenoj situaciji itd.

Svaki transportni sistem sastavljen je od transportnih uređaja (elementi sistema) koji obavljajući osnovne operacije transporta zajedno sa ostalim uređajima čine podsistem kretanja materijala. Proučavanje ovog dela sistema svodi se na proučavanje rada transportnih uređaja, njihove međuzavisnosti i sposobnosti povezivanja u sistem. U industriji najzastupljeniji uređaj koji se koristi za transport materijala je viljuškar.

Ovo mobilno transportno sredstvo se koristi za potrebe manipulacije i kretanja materijala u proizvodnim, montažnim i skladišnim sistemima. Rad viljuškara odvija se uglavnom u ciklusima. Kod njegovog rada mogu se razlikovati standardne operacije koje se pojavljuju jedanput ili više puta u okviru svakog ciklusa. U te operacije spadaju pre svih: zahvatanje materijala odnosno transportne jedinice (obično palete) koje obuhvata pozicioniranje vozila, izvlačenje/uvlačenje viljušaka, postavljanje viljušaka pod transportnu jedinicu sa podizanjem u transportni položaj (blagi nagib tereta prema vozilu zbog stabilnosti i sigurnosti pri transportu) odlaganje tereta odnosno transportne jedinice koja obuhvata pozicioniranje vozila, izvlačenje/uvlačenje viljušaka, samo spuštanje tereta, postavljanje vozila za transport bez tereta, okretanje pod 90° i 180°, podizanje ili spuštanje transportne jedinice zbog utovara ili istovara sa vozila spoljnjeg transporta ili uskladištenja u regal ili blok skladište itd.

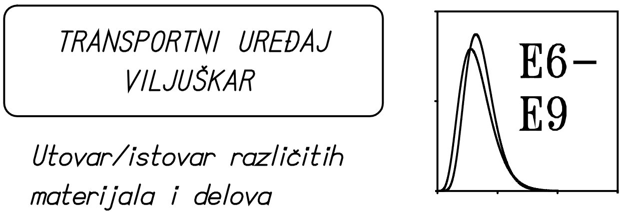
Analiza rezultata snimanja upravo ovih operacija koje su sastavni deo svakog radnog ciklusa ukazuju da je vremensko ponašanje parametara operacija najbliže teoretskoj normalnoj raspodeli, što se može videti na osnovu rezultata dobijenih snimanjem na postojećim industrijskim sistemima [8]. To znači da se ovi standardizovani elementi radnog ciklusa ponašaju po normalnoj raspodeli što ukazuje na minimalno odstupanje od srednje vrednosti. U potpunosti se za određivanje vremenskih parametara ovih operacija mogu koristiti deterministička vrednosti odnosno deterministički modeli. Analiza rezultata snimanja ovih operacija data je na slici 2.




*Sl. 2: Ciklus viljuškara - standardne transportne operacije*

Ova analiza važi za one radne cikluse koji se ponavljaju i gde se osnovni parametri ne menjaju bitno u vremenu. Ne mogu se primeniti kada se oni menjaju odnosno kada se viljuškar koristi kao transportno sredstvo između više različitih lokacija pa se javlja različiti put transporta i različiti zahtevi za transport a time i različito vreme trajanja radnog ciklusa.

Stohastika se javlja kod standardizovanih operacija utovara i kod tereta koji nisu isti po masi, gabaritu, i obliku pakovanja. U tom slučaju operacije utovar/istovar najbolje se opisuju Erlang-ovom raspodelom sa parametrom *k* koji uzima vrednosti od 6÷9 [8]. Ovaj slučaj je dosta čest kod skladišnih sistema jer se tu javlja više vrsta roba sa kojima se radi sa različitim transportnim jedinicama. Kod proizvodnih sistema ovaj slučaj se javlja samo kada su sistemi veliki i kada objedinjuju proizvodnju velikog broja različitih proizvoda koji se dalje šalju kao polufabrikati. Ova zavisnost se može grafički prikazati kao na slici 3.

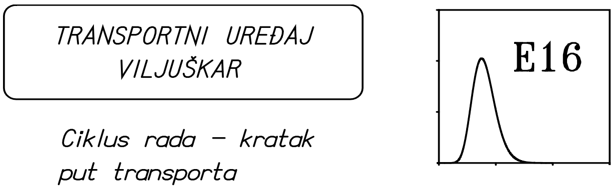



*Sl. 3: Ciklus viljuškara - operacije utovara i istovara*

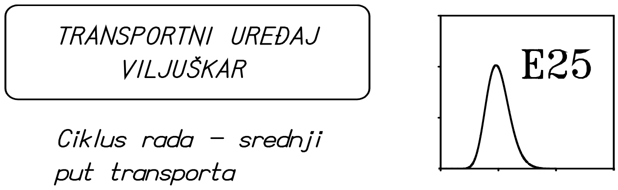
Svi dosad analizirani procesi koji su obeleženi kao standardizovani, ako se tretiraju tako da se meri broj realizovanih procesa u jedinici vremena ukazuju da se ti podaci mogu opisati normalnom raspodelom. Ova činjenica ukazuje na standardizovanost pomenutih operacija, odnosno da oni malo odstupaju od srednje vrednosti. To znači da se u proračunima mogu uzeti kao deterministički. Ovo je značajan podatak za projektovanje jer se na bazi njih može odrediti tačan kapacitet pretovara.

Sve do sada rečeno o radu viljuškara ukazuje na deterministiku pomenutih veličina, a stohastika koja se javlja kod njegovog rada očigledno je povezana sa ostalim elementima ciklusa, stohastika očigledno postoji što potvrđuje analiza podataka za rad celih sistema u kojima figurišu viljuškari kao elementi sistema. Ova činjenica odnosno pretpostavka ukazuje da deo ciklusa koji se odnosi na vreme transporta kao funkcija pređenog puta sa ili bez tereta, je onaj element koji uslovljava stohastiku i neravnomernost rada viljuškara. Ciklus transporta u odnosu na dužinu transportnog puta može se podeliti na:

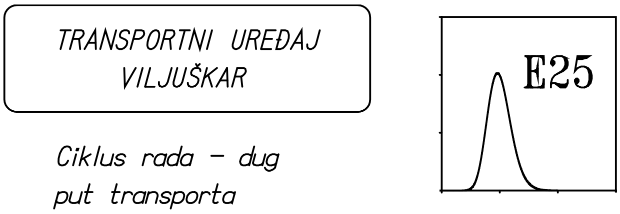
– cikluse koji imaju kratak put transporta, (pri manipulaciji na prijemno odpremnoj zoni u skladištu i proizvodnji, opsluživanju sistema sa malim brojem mašina i sl.), raspodela vremena trajanja ciklusa prikazana je na slici 4,
– cikluse koji imaju srednju dužinu transportnog puta, (rad na opsluživanju mašina sa grupnim rasporedom, transport između odeljenja u mašinskim radionicama, komunikacija skladište - proizvodnja, transport u remontnim radionicama i sl.), raspodela vremena trajanja ciklusa prikazana je na slici 5,
– ciklusi koji imaju dugačak put transporta, (transport između pogona u velikim fabrikama i sistemima koji je često vezan za transport između više odvojenih objekata i sl.), raspodela vremena trajanja ciklusa prikazana je na slici 6.




*Sl. 4: Ciklus viljuškara - kratak transportni put*




*Sl. 5: Ciklus viljuškara - srednja dužina transportnog puta*




*Sl. 6: Ciklus viljuškara - dugačak transportni put*

Ova analiza ukazuje da je stohastika u obrnutoj srazmeri sa dužinom transportnog puta i vremenom trajanja ciklusa transporta, odnosno ona je najveća kod ciklusa sa kratkim putem transporta i najkraćim vremenom trajanja ciklusa. Jedna od činjenica koja objašnjava ovako ponašanje kod vremenski kratkih ciklusa sa kratkim transportnim putem, je da poremećaji koji se javljaju u sistemu bitno utiču na sam proces. Bilo kakva nepredviđena prepreka, zastoj u radu, kvar ili neka slična nepravilnost bitno remeti i utiče na ciklus što ima za posledicu veću neravnomernost i stohastiku. Zbog kratkog transportnog puta i većeg broja ponavljanja ovih ciklusa i najmanji poremećaj u dužini puta, što je neminovno zbog tehnologije rada, utiče na ukupno trajanje ciklusa odnosno na različitu dužinu trajanja i povećanu neravnomernost. Svi pomenuti poremećaji koji su uvek prisutni pri kretanja materijala sa porastom vremenske dužine trajanja ciklusa gube od značaja da bi se kod onih sa dugačkim transportnim putem sa velikim vremenskim trajanjem ciklusa sasvim izgubio njihov uticaj i vremenski parametri težili srednjoj vrednosti odnosno, ponašali bi se po normalnoj raspodeli, i njihove vrednosti mogle da se tretiraju kao determinističke. Rezultati analize su prikazani na slici 7.

## 5. ZAKLJUČAK

Razvijena metodologija za analizu vremena trajanja radnog ciklusa i parametara radne sposobnosti može da poveća efikasnost procesa projektovanja tehničkih sistema kao i iskorišćenje mašinskih sistema, minimizuje rizik od nastajanja grešaka uzrokovanih korišćenjem neadekvatnih vremena trajanja radnog ciklusa kao i da smanji troškove razvoja i projektovanja.

Za detaljnu analizu kretanja materijala neophodno je uzeti u obzir stohastičnost procesa koji daleko realnije opisuju njegov dinamički karakter, koji se može sa dovoljnom tačnošću opisati odgovarajućim teorijskim raspodelama. Detaljna analiza kretanja materijala prikazana je na primeru radnog ciklusa viljuškara.

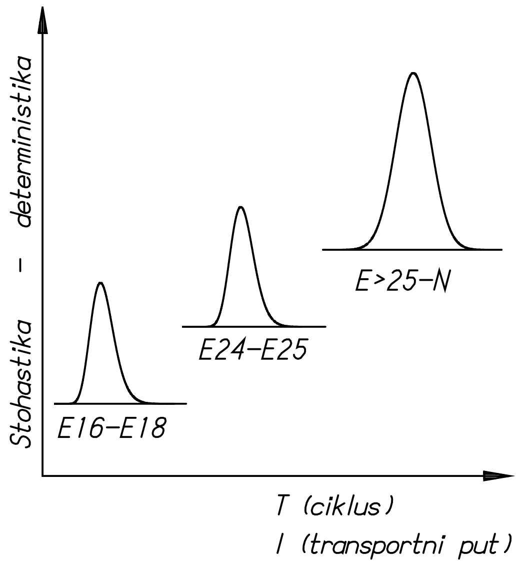
Viljuškar je uređaj koji je najčešće u primeni na poslovima koje se ciklično ponavljaju između dve lokacije u sistemu kretanja materijala. Uočava se da standardni delovi ciklusa (zahvatanje i odlaganje materijala, okretanje i sl.) mogu se opisati normalnim zakonom raspodele što znači da se mogu tretirati kao determinističke veličine.

Stohastika se kod radnog ciklusa viljuškara javlja kod utovara i istovara više vrsta roba po masi, gabaritu i obliku pakovanja.

Stohastika se javlja i kod ostalih delova ciklusa na šta ukazuje analiza celih sistema u kojima se viljuškar javlja kao element sistema kretanja materijala. Neravnomernost ciklusa viljuškara je očigledno vezana za vreme transporta u funkciji pređenog puta sa ili bez tereta.

Stohastika je u obrnutoj srazmeri sa dužinom puta transporta i vremenom trajanja ciklusa, što se može objasniti uticajem poremećaja koji se javljaju za vreme kretanja kroz sistem, a koji su veći za kraće cikluse.

Date zakonitosti imaju za cilj da pokažu opšti karakter ponašanja sistema ili uređaja i kao takve mogu se primeniti u projektovanju i analizi svih sličnih sistema i uređaja. Na taj način se kvalitet projektovanja povećava i skraćuje vreme rada jer projektant lakše ulazi u oblast realnih dobrih rešenja.




*Sl. 7: Raspodela vremena trajanja radnog ciklusa viljuškara u zavisnosti od dužine transportnog puta*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# Analyse of working cycle - case study: forklift truck

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*In this paper a new methodology for analyze of work of the single position transport machines (devices) is presented. Methodology sets theoretical basis for developing new methods for obtaining most precise behaviour of average working cycle as well as methods for analyze of technological function parameters of transport machines (devices). Analyze of the working cycle of forklift truck is used as an example for usage of presented methodology. Cumulative density functions of forklift truck working cycle duration are presented, based on significant analyzed parameters.*

**Keywords: system approach, methodology, working cycle, forklift truck**

## 0. INTRODUCTION

Usually, particularly among engineers, expression "design" is used as a synonym for creation of (new) physical systems - hardware. However, generally design as a activity is related to creation of physical products (of any kind - in that frame especially technical, or first technical if we talk about engineers) as well as creation of such objects - design subjects like processes, procedures, methods, organizations i.e. software - soft systems.

Design of objects from different areas requires numerous different methodologies, general and particular methods of analysis, synthesis, evaluation and optimization of system properties - attributes and its parts (elements).

Classical methods gave expected results (effects) - which could be gained as a best, according to available means and knowledge.

Things are changing, for instance new mathematical instruments and tools are developed and according to that, methods which are use those instruments and tools can be also improved.

Development of new knowledge as well as capabilities of computer technology, new approaches in problem solving and corresponding development of new methods, ensures significant increase of possibility that optimal solutions can be found and therefore to increase effects of activities in the design of complex systems.

However, design as activity and discipline, opens many fields of wide programs and special research projects and finding solutions for new methods in design.

Development of new methods always becomes from need for improvement of possibilities that real solution for problems, which are subject of design, can be obtained, from one side, as well as from realizing the possibilities which are given by partly used tools i.e. mathematical models developed for working out - solving stochastic problems. Transportation processes are classical example of stochastic problems.

If some developed methodologies are successfully applied in one area, it does not mean that they can be generally used for solving other and different design tasks. There are no universal methodologies and methods. This fact leads to problem of proper choice of the methodology i.e. method for solving each particular design task and/or its parts, and to need for research, development and design better methodologies and methods. [6]

Checkland, generalizes idea of system approach (methodology) from realization of industrial systems ("hard systems") which has goals that can be relatively easy defined, clearly defined decision making procedures and performances that can be easily measured, towards the realization of so called "soft systems" (real word problem solving) which goals is hard to define, where decision making procedures are not certain while the evaluation of performances is in best case qualitative (management, marketing etc.). [4]

Developed methodology of real word problem solving is presented on figure 1.

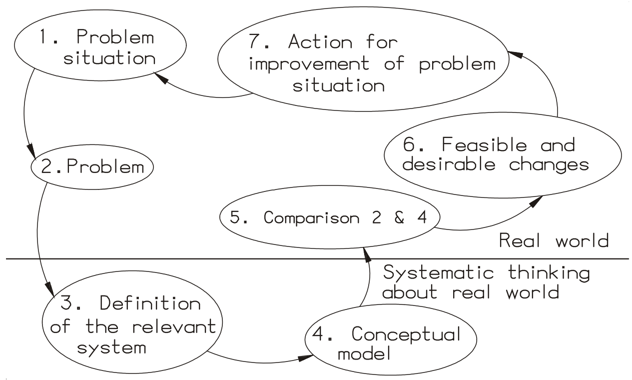


*Fig. 1: Methodology of real word problem solving*

## 1. DEVELOPMENT OF METHODOLOGY FOR ANALYSIS AND OPTIMIZATION OF WORKING CYCLE TIME

According to approaches and ways – methods, which are in use in design practice of the technical systems today, in this paper effort is focused on need for improvement of methods for analysis and optimization of the system performance parameters (technological functions). From that frame, subject of studying and development of new method is, among other, working cycle time as one of main performance parameters of special class of working machines known as single-position machines with discontinue working regime.

Description of the problem is given on the example of concrete technical system, design and construction of transportation system, of specified class.

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At the designing of the transportation systems, two characteristic cases, taking into account duration time of the working cycle can happen:

1. Choosing and dimensioning (phase of planning and preliminary design of the system) of the devices on the basis of the longer calculated working cycle time, has for consequences:
   - bigger investments in equipment (transportation machines) i.e. enlarged number of machines or enlarged capacity of the machine,
   - enlarged number of operators and workers on transport,
   - less utilization of the machines and work.
2. Choosing and dimensioning of the device on the basis of the shorter calculated working cycle time, has for consequence
   - smaller investment in transportation equipment (transportation machines),
   - bottle necks,
   - difficulties in planning and usage of the system, need for new investments in transportation equipment,
   - bigger manufacturing cycle time, as a result of stoppage in the process, waiting for some operations etc.

Machine performances – working capacity, working ability of the system i.e. transport machines, in given time period and for given working conditions depends on transport unit size as well as on working cycle time. According to chosen transport unit, capacity of device (machine) is determined, while according to points of material (transport unit) picking and discharging, operations of working cycle are defined.

For different points of material discharging according to one point (or more points) of material picking, paths of material transfer have different lengths and different shapes. Working cycles, defined in such a way have different duration times which are randomly ordained in specific period of work – hour, shift, month etc. According to this work of such machines has stochastic nature. Total transportation task for specific period of time, total amount of material which should be transferred from starting points to points of discharge and capacity of one machine, determine the needed number of machines.

Organization and perform of specific working cycles, chosen velocites of material transfer i.e. velocity of execution of specific operations, determine the durations of those working cycles. Precise calculation of working cycle duration enables reliable choice of transport units, capacity and number devices (machines) for given transportation task. [3]

## 2. DEFINITION OF WORKING CYCLE

In further text, working cycle of, so called, single-position machines with discontinue working regime will be defined. Single-position machine is such type of machine which handle only one peace - product at the time and it is all time on machine during handling. [1]

In the work of each machine there are mutually connected operations of different kind such as:

- placement of the material on the machine,
- basic technological operations,
- transport operations (movement of the material and people, defining of the paths and speeds),
- removing of the material from the machine,
- checking,
- tools replacement,
- demands and limitations for possible moving overlapping,
- external and internal losses of time,
- regulations, etc.

Total time of all operations of technological process – basic and auxiliary, which are not mutually overlapped according to time schedule, defines time needed for technological process to be executed, so called **Technological cycle** of the machine - $T_t$. Independently from this, in most cases, it is possible to define other important interval of time $T_r$, this interval of time is beetwen moments when two successively handled products leave machine and it is called **Working cycle** of the machine (or system generaly). It represents interval of time needed for handling of one peace - product.

In the case when only one peace - product at the time is handling on the machine, times of Technological cycle and Working cycle are equal: $T_t = T_r$.

Operations of Technological cycle can be executed: step by step (one after another), parallely (all operations at the same time) and as combination of previous two ways (certain number of operations is executed step by step and certain at the same time).

According to previous text, Technological cycle time and Working cycle time, for transportation machines are:

- for machines at which working object is all time of handling in one possition and while handling of one product is not finished it is impossible to put another product on the machine:

  $$T_t = T_r = t_{ps} + \Sigma t_r - \Sigma t_{pr} + \Sigma t_g,$$

  where are:

  $t_{ps}$ – putting and removing time,

  $\Sigma t_r$ – moving of working mechanism (duration of some working operations),

  $\Sigma t_{pr}$ – overlapping times of some operations,

  $\Sigma t_g$ – times of internal and external losses.
- for machines at which all operations are executed parallely:

  $$T_t = T_r = t_{ps} + t_{rmax} + \Sigma t_g.$$
- for machines at which certain number of operations is executed step by step and certain at the same time, technological cycle times and working cycle times are calculated as a combination of previous two times.

Analyze and optimization of Working cycle time, which defines total capacity - working power of the machine (functional performances), in the cases of machine work when the same technological i.e. working processes are always repeated is not a problem.

Problem arises when working cycles are different and randomly distributed according to: working (handling, transport etc.) object and duration of Technological i.e. Working cycles of transport operations - picking and discharging points of material are different.

Here we find problem of average working cycle definition and task of development of new methods for calculating Working cycle time for complex stochastic transport tasks, which are usually present in designer practice in choosing and dimensioning of transport and generally all other machines with discontinue regime of work. In this case special (computer) procedures, based on stochastic models, for determining average optimized Working cycle of transport devices, has to be developed.

Generally, Working cycle of single-position machines has specific characteristics, especially underlined in the case of transportation devices (machines) which belongs to this class of machines. One of those characteristics is that, exactly determined, minimal and maximal Working cycle always exist. This can be explained with the fact that Working cycle of single - position transportation machines consists of operations, which has to be executed in each Working cycle independently of transport device movement.

## 3. DETERMINING OF THE PERFORMANCES - WORKING ABILITY OF THE SYSTEM

Incorporation of the procedures for defining working cycles parameters, by introducing developed methods for analysis and optimization, in the algorithm for determining parameters of the technological function - working ability of the machine (devices, systems) with discontinue working regime (single position technological, transport and other machines), assumes observation of work of given device in appropriate - critical intervals of time. Critical in the sense that those intervals are relevant for dimensioning of the given device.

One of important factors which is relevant for determination of parameters of the technological function is, among all, state of given device (system) at the beginning of critical intervals. Initial state is causing non-stationary working regime of the system. Duration of the non-stationary working regime depends on initial conditions and generally it does not depend on duration of observed critical interval i.e. non-stationary regime of system work can be either longer or shorter from duration time of observed critical interval. This practically means that system can work in non-stationary regime during whole critical interval or system can work one part of the critical interval duration time in non-stationary working regime and other in stationary working regime, which has affect on parameters of technological function. Parameters of technological function - working ability of the system (device) in non-stationary working regime is time dependent while that is not a case in stationary working regime.

For obtaining parameters of the technological function - working ability of the system (device) proper queuing theory models and simulation programs can be used.

## 4. MATERILAL FLOW - ANALYSIS OF FORKLIFT TRUCK WORKING CYCLE

System of internal transport presents solution to problem of material flow for particular design task. Usually it results as integrated set of operations, activities and flow of information, tightly connected in order to carry out function in a way which is feasible and economically justified.

In order for these systems could work smoothly they must have adequate capacity. Deviation from the optimum capacity leads to inefficient utilization of the equipment (more devices than it is necessary), or to the creation of large number of queues (less devices than required), or the build-up of material in the individual stages of the process. The task of the designer is to properly set up the material flow system to meet the required capacity. For this purpose, the appropriate process models that allow the finding of such a structure of the transport system to meet the conditions set transport task. [3]

It is necessary to have a variety of information about the process to be able to use mathematical models. For the application of deterministic models is necessary to know all the input parameters and their dependencies, while for the application of stochastic models it is necessary to know the distribution - cumulative density function (cdf) of relevant time parameters (character of change). Distribution (cdf) of relevant time parameters can be reached by recording them on systems that are in operation. [7]

For the designer who is working on establishing a new system, knowledge about the distributions of relevant parameters in similar systems is important because based on them he can use appropriate models to predict the behaviour of newly designed system. By applying the appropriate distributions, basic indicators of the work of the new system in the desired situations, can be obtained.

Knowledge of these parameters enables the use of known stochastic models. Most models used in the area of material flow are queuing theory models. They are particularly suitable for studying the servicing systems such as internal transport systems, warehouse systems etc. In addition to these models, simulation method is often used for analyzing internal transport flows. Simulation of the material flow system makes it possible to examine in detail the individual elements of the transport system as well as the whole transport system.

The advantage of the simulation method in respect to the analytical models is that simulation methods often gives more accurate results and do not require expensive and time-consuming verification of the obtained results in exploitation conditions.

The problem of designing a system of material flow is conditioned by the knowledge of the production demands and specific exploitation conditions. Every production system which has a transport system is a unique problem. For the assessment of the behaviour of new designed systems, data on similar derived systems can only be used. So it is reasonable to analyze work of the existing systems and to set up relations between the individual system classes, applied devices, i.e. to know the corresponding technological functions parameters. Usage of these technological function parameters leads to the average behaviour of the system under examination.

Analysis of material flow should start from an analysis of time parameters of work because their knowledge can define the activities of the transportation system. Time parameters that are important for the work of this subsystem are: duration of the average working cycle with defined differences and degree of unevenness, number of executed cycles with defined peak number per time unit, time parameters for connecting several devices in a transportation subsystem (waiting time at the point of loading etc.), needed time to accomplish the transportation task and therefore the required number of devices that need to work, the probability that the system is in a particular situation (state), etc.

Each transportation system is composed of the transportation devices (elements of the system), which by performing the basic transport operations together with the other devices constitute the subsystem of material flow. The study of this part of the system is reduced to the study of the work transportation devices, their interdependence and the ability to connect to the system. In industry, the most common device used for the transport of materials is forklift truck.

This mobile transport device is used for the manipulation and movement of materials in manufacturing, installation and warehouse systems. Work of forklift trucks takes place mainly in cycles. In its work standard operations that occur once or several times within each working cycle, can be distinguished. These operations are, first of all: loading of material or a transport unit (usually a pallet) which includes a vehicle positioning, extraction/retraction of forks, positioning of forks under a transport unit with lifting to the transportation position (a slight slope of the load toward the vehicle due to the stability and safety during transportation), unloading of the cargo or a transport unit which includes vehicle positioning, extraction/retraction of forks, lowering of the load, positioning of the vehicle for the transport without load, vehicle turning under 90° and 180°, lifting or lowering of the transport unit for loading or unloading to/from the external transport vehicle, warehouse rack, block storage, etc.

Analysis of the results, obtained by recording, of these particular operations which are an integral part of every working cycle indicates that the time behaviour of operation parameters is nearest to the theoretical Normal distribution, as can be seen from the results obtained by surveying the existing industrial systems [8]. This means that these standardized elements of the working cycle behave upon the Normal distribution which indicates the minimum deviation from the mean. For determining time parameters of these operations, deterministic value or deterministic models may be fully used. Analysis of recording results of these operations is given in Figure 2.

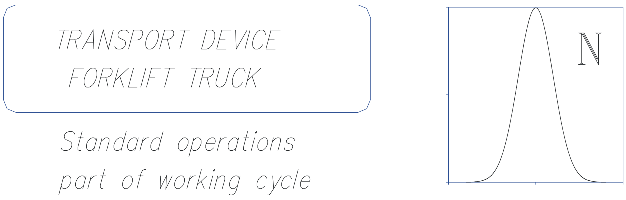


*Fig. 2: Forklift truck cycle - standard transport operations*

This analysis applies to those working cycles that are repeated, and where the basic parameters do not change substantially over time. It can not be applied when basic parameters change in time i.e. when the forklift is used as a transportation device between different locations where appears different transportation path, different requirements for transport and hence different working cycle time.

Stochastic occurs in the standardized operation of loading when cargo vary according to weight, dimensions, and shape of the packaging. In this case, the best way to describe loading/unloading operations is by Erlang distribution with parameter *k* which takes a value between 6÷9 [8]. This case is quite common in the warehouse systems because there are more types of goods involved with different transport units. In manufacturing systems this case occurs only when systems are complex (big) and when combine the production of a wide variety of products that are further sent as semi-finished products. This dependence can be represented graphically as in Figure 3.

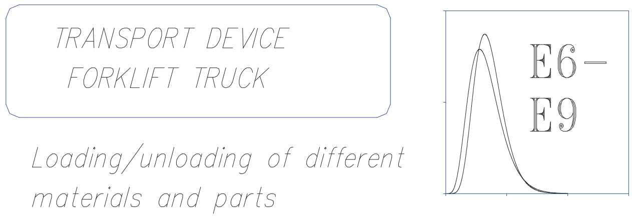


*Fig. 3: Forklift truck cycle - loading and unloading operations*

All previously analyzed processes that are marked as standardized, if they are treated like measured number of processes per unit of time indicates that the data can be described by a Normal distribution. This fact indicates mentioned operations are standardized, and that they differ little from the mean. This means that in the calculations it can be taken as deterministic. This is important information for the design because based on them exact capacity of reloading can be determined.

Until now all presented about the work of forklift truck indicates that mentioned parameters are deterministic, while stochastic, which occurs in its work is obviously linked with other elements of the cycle. Stochastic obviously exists what confirms data analysis of the whole systems work in which forklift trucks exists as elements of the system. This fact i.e. assumption points out that part of the working cycle which refers to the transportation time as a function of path distance with or without a load, is the element that causes stochastic and uneven in forklift truck work. Working cycle in relation to the length transport path can be divided into:

– cycles which have a short transport path (manipulation in input/output zone in warehouse, production, servicing of the system with a small number of machines etc.), the distribution of the working cycle time is shown on Figure 4,
– cycles which have a mean length of transport path (servicing of machines with group layout, transport between the departments in a machine workshops, communication warehouse - manufacturing, transport in repair facilities etc.), the distribution of the working cycle time is shown on Figure 5,
– cycles which have a long transport path (transport between facilities in large factories and systems, often related to transport between several separate buildings, etc.), the distribution of the working cycle time is shown on Figure 6.

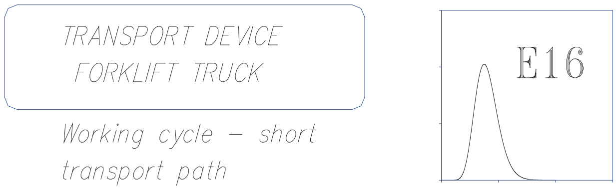

*Figure 4: Forklift truck cycle - short transport path*

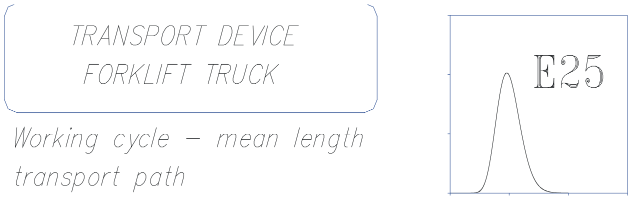

*Fig. 5: Forklift truck cycle - mean length of transport path*

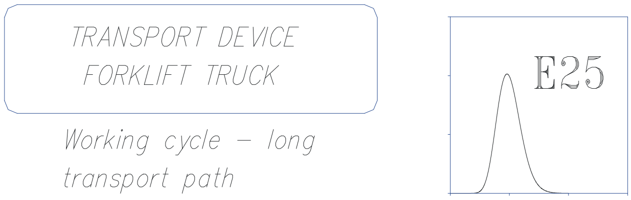

*Fig. 6: Forklift truck cycle - long transport path*

This analysis indicates that the stochastic is in inverse proportion to the length of the transport path and duration of working cycles of transport, i.e. it is highest for the working cycle with a short transport path and the shortest cycle time. One of the facts that explain such behaviour at short working cycles with a short transport paths, is that disorders that occur in the system have significant impact on the process. Any unforeseen obstacles, downtime, failure or some such irregularity substantially disrupts and affect the cycle which results in more uneven and stochastic. Due to short transport paths and a number of repetitions of these cycles even the least disturbance in the transport path length, which is inevitable due to work technologies, influence the total working cycle time i.e. different duration and the increased unevenness. Effects of all mentioned disorders which are always present in the movement of material, with the increase of the working cycle time has less importance until working cycles with a long transport path where its importance is completely lost. In that case time parameters tend to their mean values and they can be described by Normal distribution, and their value could be treated as deterministic. The results of analysis are shown in Figure 7.

## 5. CONCLUSION

Developed methodology for analyze of the working cycle duration time and parameters of the working ability can increase efficiency of the design process of technical systems and utilization of the mechanical systems, minimize the risk of errors obtained by using inappropriate working cycle duration time and cuts the cost for research and design.

For a detailed analysis of the material flow is necessary to take into account process stochastic behaviour which describe far more realistic its dynamic character, which can be described with sufficient accuracy with adequate theoretical distributions. Detailed analysis of the material flow is presented through example of forklift truck working cycle.

The forklift truck is a device that is commonly used in transport operations that are repeated cyclically between two locations in the system of material flow. It is observed that the standard parts of the cycle (loading and unloading of material, turning, etc.) can be described by Normal distribution, which means that they can be treated as deterministic values.

Stochastic at forklift truck working cycle occurs in process of loading and unloading of more types of goods which differ in weight, dimensions and shape of the packaging.

Stochastic at forklift truck working cycle occurs also in other parts of the cycle as indicated by analysis of the whole system in which a forklift truck is a part of material flow. The unevenness of forklift truck working cycle is obviously related to the transport time as a function of transport path length, with or without load.

Stochastic is in inverse proportion to the transport path length and cycle time, which can be explained by the influence of disorders that occur during movement through the system, which are higher for shorter cycles.

Presented relations intended to demonstrate the general character of the behaviour of the systems or devices, and as such, can be applied in the design and analysis of all similar systems and devices. In this way, the quality of design increases and reduces design time because the designer easily enters into the area of real good solutions.

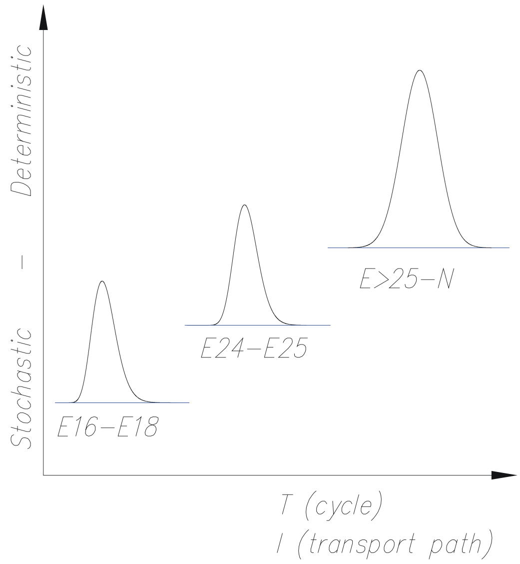

*Fig. 7: Distribution of the forklift truck cycle time depending on length of transport path*

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