Pregledni rad

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MODELI SISTEMSKE DINAMIKE U REŠAVANJU UPRAVLJAČKIH PROBLEMA

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U Sistemskoj dinamici (SD), kao funkcionalističkoj sistemskoj metodologiji, modeli predstavljaju ključni metodološki instrument za rešavanje upravljačkih problema. Reč je, pre svega, o matematičkim modelima, izgrađenim na osnovu odgovarajućih feedback struktura, tj. određenih elemenata i tokova koji formiraju feedback petlje. Budući da je SD zasnovana na pretpostavci da struktura sistema predstavlja ključnu determinantu ponašanja, modeli SD obezbeđuju efektivno predviđanje budućeg ponašanja sistema. U radu je fokus na procesu modeliranja u SD, kao složenom, iterativnom procesu koji se sastoji od sledećih faza: konceptualizacije, formulacije, testiranja i implementacije modela. Iako su izuzetno korisni za rešavanje brojnih problema upravljanja u organizacijama, modeli SD poseduju određene nedostatke kao posledicu, pre svega, njihove kvantitativne prirode. U otklanjanju ograničenja modela SD od odgovarajuće važnosti su kvalitativno i grupno modeliranje, kao mogući pravci daljeg razvoja SD.

Ključne reči: Sistemska dinamika, proces modeliranja, modeli Sistemske dinamike, rešavanje upravljačkih problema

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UVOD

U istraživanju i rešavanju savremenih upravljačkih problema, tj. problemskih situacija mogu se primeniti različiti sistemski pristupi i metodologije. Kao odgovarajuća sistemska metodologija, Sistemska dinamika (SD) je primerena upravljačkim problemskim situacijama sa svojstvima kompleksnosti i unitarnosti. Shodno tome, a vodeći računa o ključnom određenju SD – usmerenost na istraživanje feedback strukture koja generiše određeno ponašanje sistema – SD

predstavlja relevantan strukturalističko-funkcionalistički sistemski pristup menadžmentu. Osnovni iskazi upravljačkih problemskih situacija u SD su struktura i procesi unutar nje, a ključni instrumenti u rešavanju upravljačkih problema su odgovarajuće razvijeni modeli. U tom smislu, predmet istraživanja u radu biće proces modeliranja u SD, tj. modeli SD kao relevantni instrumenti rešavanja upravljačkih problema u savremenim organizacijama.

Cilj rada je pokazati mogućnosti SD, tj. njenih modela u bavljenju i rešavanju savremenih upravljačkih problema. Zapravo, cilj je pokazati načine na koje SD može da pomogne menadžerima u kretanju kroz odgovarajuća problemska područja, predviđanju

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budućeg ponašanja i dizajniranju određenih politika unapređenja funkcionisanja organizacija.

Ključna hipoteza od koje se u radu polazi je: Ukoliko struktura predstavlja ključnu determinantu ponašanja sistema, onda modeli SD – kroz odgovarajuće kompjuterske simulacije – obezbeđuju predviđanje budućeg ponašanja istraživanog sistema.

Vodeći računa o opredeljenom predmetu, cilju i hipotezi, u radu su najpre predstavljena ključna određenja SD kao funkcionalističkog sistemskog pristupa menadžmentu. Zatim je istražen proces modeliranja u SD, odnosno specificirane su određene karakteristike i faze procesa modeliranja. Pošto je fokus na samom procesu modeliranja, posebno je razmatrana svaka faza - konceptualizacija, formulacija, testiranje i implementacija. Budući da je reč o instrumentima sa izuzetnim aplikativnim potencijalom, u radu je ukratko ilustrovan model SD na primeru prihvatanja novog proizvoda na tržištu. Konačno, identifikovane su određene manjkavosti modela SD, kao i mogući pravci daljeg razvoja SD kroz kvalitativno i grupno modeliranje.

SISTEMSKA DINAMIKA - FUNKCIONALISTIČKI SISTEMSKI PRISTUP MENADŽMENTU

Sistemska dinamika, kao sistemski pristup rešavanju upravljačkih problema, oslonjena je na teoriju informacionog feedback-a i kontrole. Fokus SD je na problemima koji se mogu modelirati kao sistemi esencijalno sastavljeni od različitih elemenata i tokova, tj. odnosa između elemenata koji formiraju feedback petlju i predstavljeni su kao kontinuelni procesi. Za takve sisteme razvijene su odgovarajuće determinističke modelske strukture, koje se ne razvijaju tokom vremena. SD modeliranje i simulacija su široko upotrebljeni u području društvenih, a posebno ekonomskih sistema, i različitih tipova organizacija, sa naročitim naglaskom na analizu politike i dizajna.

J. W. Forrester (1972) postavlja osnove Sistemske dinamike, koja je originalno naslovljena kao Industrijska dinamika. SD se bavi vremenski izmenljivim

interakcijama različitih delova upravljačkog sistema da bi se utvrdio način na koji organizaciona struktura, politike, vremenska kašnjenja u odlukama i akcijama međudejstvuju, utičući na uspeh sistema.

Budući da su upravljačke problemske situacije reprezentovane odgovarajućim strukturama i procesima unutar nje, u teorijskom smislu, za SD je ključno sledeće (Petrović, 2010, 369): Ponašanje sistema prevashodno je uslovljeno njegovom strukturom. Pri tome, pretpostavlja se da struktura i procesi koji su predmet razmatranja mogu biti predstavljeni odgovarajućim dijagramima i matematičkim modelima sistema. Prema teoriji SD, mnoštvo varijabli postojećih složenih sistema postaje kauzalno povezano u odgovarajućim feedback petljama. Sistemske veze između feedback petlji konstituišu strukturu sistema, i upravo je ta struktura ključna determinanta ponašanja sistema (Jackson, 2003, 67).

Kao esencijalni agregat SD, strukturu determiniše (Petrović, 2010, 370-371): red, smer *feedback*-a, nelinearnost i višestrukost petlji. Broj nivoa, tj. broj varijabli upotrebljen za reprezentovanje strukture istraživanog sistema određuje red sistema. Sa stanovišta usmerenosti, feedback može biti pozitivan ili negativan; pozitivan feedback uzrokuje povećanje, tj. kreiranje rasta ili pada, a negativan znači određeno sprečavanje ili kontrolisanje uticaja. Nelinearno povezivanje pozitivnih i negativnih petlji može dovesti do promena u dominaciji petlji, dopuštajući kontrolisani rast. Upravljačke problemske situacije su, po pravilu, reprezentovane strukturama sa višestrukim pozitivnim i negativnim petljama. Pretpostavka je da se na osnovu specificiranih svojstava strukture može ostvariti efektivno predviđanje i kontrola. Naime, vremenski utemeljeni matematički modeli SD simuliraju moguće scenarije funkcionisanja organizacija i tako obezbeđuju odgovarajuće projekcije trendova. Polazeći od toga da je izvršeno predviđanje pouzdano, fokus se, zatim, pomera na uvođenje odgovarajućih politika kontrole.

Uz predviđanje i kontrolu u SD, od ključnog značaja je model SD. Njegovi osnovni agregati su nivoi i stope. Pod nivoom se podrazumeva veličina koja se tokom vremena menja. Odnosno, to su sadašnje vrednosti varijabli, tj. vrednosti koje rezultiraju iz akumulirane razlike između priliva i odliva (Forrester, 1972, 68). Za

razliku od nivoa, stope definišu sadašnje tokove između nivoa u sistemu. Stope korespondiraju sa aktivnošću dok nivoi mere rezultirajuće stanje u kojem se sistem našao delovanjem dotične aktivnosti. Na primer, broj zaposlenih predstavlja nivo koji je određen stopom zapošljavanja i stopom otkaza ili nivo duga određen stopom pozajmljivanja i stopom otplate itd. (Sterman, 2000, 200).

Matematički iskaz modela SD reprezentovan je sistemom jednačina (jednačine nivoa i stopa) kojim se kontrolišu interakcije varijabli razmatrane problemske situacije koje se tokom vremena menjaju. Pošto se modelirani sistem kreće u vremenu, potrebno je periodično obračunavanje dotičnih jednačina. Kao podrška SD modeliranju i simulaciji razvijeni su različiti softveri poput: DYNAMO-a, Powerism-a, Venism-a itd.

PROCES MODELIRANJA U SISTEMSKOJ DINAMICI

Modeliranje, kao sastavni deo procesa učenja u organizacijama, predstavlja iterativni, kontinuirani proces formulisanja, testiranja i revizije, kako formalnih tako i mentalnih modela. Kao odgovarajući iskazi upravljačkih problemskih situacija, modeli predstavljaju moćan instrument identifikovanja i reprezentovanja njihovih ključnih određenja, načina na koji se manifestuju i njihovih relevantnih implikacija. Shodno tome, validni modeli su izuzetno koristan metodološki instrument u upravljanju organizacijama, odnosno u opredeljivanju načina kretanja menadžera kroz upravljačka problemska područja savremenih organizacija (Petrović, 2010, 572). Cilj modela SD je da se identifikuju politike i organizacione strukture koje unapređuju funkcionisanje i obezbeđuju uspeh organizacija.

Proces modeliranja u SD treba da bude fokusiran na važna pitanja, tj. na ključne probleme u organizaciji i sastavni je deo organizacionog i društvenog konteksta. Pre nego što proces modeliranja otpočne, modelar mora da ima pristup organizaciji i da identifikuje klijente. Reč je o pojedincima ili grupama na čije ponašanje utiče proces modeliranja, tj. čije se ponašanje mora menjati da

bi se rešio problem. Proces modeliranja treba da bude konzistentan sa klijentovim veštinama, mogućnostima i ciljevima. Iako je većina klijenata zainteresovana za to da modeli podrže zaključke do kojih se već došlo ili da služe kao instrumenti moći u organizaciji, modelar mora da bude spreman na to da klijentima saopštava da su njihove pretpostavke bile pogrešne ako je to ono što se otkrije modeliranjem (Sterman, 2000, 84-85).

Model SD treba da poseduje sledeće karakteristike (Forrester, 1972, 67):

- da može da opiše bilo koji problem u uzročno-posledničnim odnosima;
- da bude relativno jednostavno matematički iskazan;
- da ima mogućnost da obuhvati brojne varijable, sve dok je to u granicama praktičnih mogućnosti kompjutera;
- da bude sposoban da upravlja različitim diskontinuitetima tako da to ne utiče na rezultate, ali i da bude sposoban da generiše diskontinualne promene u odlukama kada je to potrebno.

Takođe, model SD poseduje i sledeća određenja (Forrester, 1972, 68): sastoji se od nekoliko nivoa, obuhvata tokove koji prenose sadržaje od jednog nivoa do drugog; obuhvata funkcije odlučivanja koje kontrolišu stopu toka između nivoa i sastoji se od informacionih kanala koji povezuju funkcije odlučivanja sa nivoima.

Modeliranje u SD predstavlja proces koji se sprovodi kroz nekoliko faza, koje različiti autori na različite načine klasifikuju.

Luna-Reyes & Andersen (2003, 275) specificiraju faze procesa modeliranja prema različitim autorima. U tom smislu, mogu se izdvojiti sledeće klasifikacije: konceptualizacija, formulacija, testiranje i implementacija; zatim: definisanje problema, konceptualizacija sistema, formulisanje modela, analiza ponašanja modela, analiza politike i korišćenje modela; ili: konstruisanje dijagrama i analiza, faza simulacije (prva etapa) i faza simulacije (druga etapa).

Takođe, Sterman (2000, 86) klasifikuje faze procesa modeliranja na sledeći način: artikulisanje problema,

formulisanje dinamičkih hipoteza, formulisanje simulacionog modela, testiranje modela i formulisanje politika i implementacija.

Uprkos različitim klasifikacijama pojedinih faza, generalno, proces modeliranja u SD obuhvata sledeće aktivnosti (Jackson, 2003, 68-69): Pre svega, faza konceptualizacije u kojoj se razjašnjava problem i identifikuju varijable koje na njega utiču. Zatim se gradi model feedback petlje koji otkriva odnose između varijabli. Takav model se, u fazi formulacije, dalje razvija u odgovarajući matematički model, tj. razvijaju se jednačine nivoa i stopa, kojima se uz pomoć određenih softvera, obezbeđuje relevantna kompjuterska simulacija ponašanja sistema. U fazi testiranja procenjuje se validnost modela, a u fazi implementacije se identifikuju mogući načini poboljšanja rezultata funkcionisanja sistema, tj. dizajniraju određene politike.

Cilj faze konceptualizacije je da se izgradi konceptualni model koji reprezentuje relevantan problem u sistemu. U fazi konceptualizacije potrebno je sprovesti sledeće aktivnosti (Albin, 1997, 6):

- definisati svrhu modela;
- opredeliti granice modela i identifikovati ključne varijable;
- opisati ponašanje sistema, tj. izgraditi referentni model ključnih varijabli i
- dijagramski predstaviti feedback petlje sistema.

Najvažniji korak u procesu modeliranja je definisanje problema, odnosno postavljanje svrhe modela. Svaki model je neka reprezentacija sistema. Da bi bio koristan, model treba da se bavi specifičnim problemom i da pojednostavljuje, a ne da detaljno odslikava sistem. Korisnost modela leži u činjenici da oni pojednostavljaju realnost kreirajući reprezentaciju onoga što može da se razume (Serman, 2000, 89). Modelar, takođe, treba da razmotri kome je model primarno namenjen, a od esencijalne važnosti je postizanje saglasnosti oko svrhe modela. Bez jasne i striktno definisane svrhe veoma je teško odlučiti koje komponente sistema su važne. Ukoliko se svrha odredi suviše široko ili apstraktno, u model će biti uključeno previše komponentata i biće suviše kompleksan za bilo kakvu praktičnu analizu.

Greške koje se najčešće javljaju u opredeljivanju svrhe modela su (Albin, 1997, 9):

- svrha ne uspeva da omogući razumevanje sistema;
- svrha ne otkriva politike koje će unaprediti ponašanje sistema;
- svrha ne odražava mentalne modele i ne služi kao sredstvo komunikacije i unificiranja.

Nakon izbora problemskog područja na koje se treba fokusirati, modelar mora da prikupi relevantne podatke i da definiše model. Što se tiče granica modela, potrebno je istaći da feedback sistem poseduje zatvorene granice u okviru kojeg se generiše određeno ponašanje koje se analizira. Pre svega, modelar mora da istraži sve komponente koje smatra neophodnim za model sistema. Reč je o inicijalnoj listi komponentata. Zatim, da bi se dalje specificirale granice modela, modelar mora da podeli inicijalnu listu komponentata na dve važne grupe (Albin, 1997, 10; Serman, 2000, 97):

- endogene – dinamičke varijable uključene u feedback petlje sistema i
- egzogene – komponente čije vrednosti ne utiču direktno na sistem.

Pošto se izdvoje ove dve grupe komponentata potrebno je odrediti koje su komponente nivoi, a koje stope. Pri tome, treba istaći da egzogene komponente ne mogu biti nivoi ili stope, već samo odgovarajuće konstante (Albin, 1997, 11). U SD se teži endogenom objašnjenju fenomena, kao i tome da se problem dinamički opiše, tj. da se opiše kao odgovarajući način ponašanja, koji se razvija tokom vremena. Vremenski interval bi trebalo da bude tako određen da obuhvati dovoljno informacija o prošlosti da bi se pokazalo kako je problem nastao i opisali njegovi simptomi. Takođe, treba da uključi relevantne informacije o budućnosti da bi se obuhvatili odloženi i indirektni efekti potencijalnih politika. Ključna teškoća u mentalnim modelima je tendencija da se razmišlja o uzrocima i posledicama kao o lokalnim i trenutnim. U dinamičkim, kompleksnim sistemima uzrok i posledica su udaljeni u vremenu i prostoru, što podrazumeva feedback sisteme sa velikim kašnjenjima, udaljenim od tačke odlučivanja ili simptoma problema (Serman, 2000, 91).

Kada se opredele granice modela i odredi vremenski interval, gradi se referentni model, odnosno skup dijagrama koji pokazuje kako problem nastaje i kako može da evoluirati u budućnosti. Referentni model, zapravo, predstavlja ponašanje ključnih varijabli tokom vremena i može da bude koristan i pre i posle izgradnje modela. Referentni modeli se mogu menjati tokom procesa modeliranja, a na osnovu inicijalnog referentnog modela, modelar može da preispita i ponovo definiše svrhu modela.

Poslednji korak u fazi konceptualizacije je predstavljanje feedbackstrukture sistema. U reprezentovanju feedback struktura, SD koristi različite vrste dijagrama. Reč je o dijagramima sa uzročnim petljama, dijagramima nivoa i stopa, strukturnim dijagramima i dijagramima strukture politike (Lane, 2008, 9). U radu će biti ukratko razmatrani dijagrami sa uzročnim petljama i dijagrami nivoa i stopa, kao najčešće korišćeni instrumenti dijagramskog predstavljanja strukture sistema u SD.

Dijagrami sa uzročnim petljama (DUP) pokazuju, pre svega, usmerenost feedback-a, kao i ključne elemente, odnosno varijable i njihove međusobne uticaje. Varijable su povezane uzročnim vezama, prikazanim odgovarajućim strelicama. U dijagramu sa uzročnim petljama, odnosi koji produkuju promenu u istom smeru (bilo rastuću ili opadajuću) označeni su pozitivnim znakom. Pozitivna feedback veza znači da ako uzrok raste, efekat takođe raste iznad onoga što bi se inače dogodilo. Takođe, ako se uzrok smanjuje, efekat se smanjuje ispod onoga što bi se inače dogodilo. Nasuprot tome, negativna feedback veza znači da ako uzrok raste, efekat se smanjuje ispod onoga što bi se inače dogodilo; i ako se uzrok smanjuje, efekat raste iznad onoga što bi se inače dogodilo (Sterman, 2000, 139).

Dakle, svaka veza se odlikuje određenom polarnošću, tj. smerom efekta koji utičuća varijabla ima na varijablu na koju se utiče (Lane, 2008, 5). Time se opisuje struktura sistema, a ne ponašanje varijabli. Odnosno, time se opisuje ono što bi se dogodilo ukoliko bi došlo do neke promene, a ne ono što se stvarno dešava. Od odgovarajućeg značaja je i prethodno navedeni izraz iznad ili ispod onoga što bi se inače dogodilo, zato što rast ili smanjenje uzročne varijable ne mora nužno da znači rast ili smanjenje efekta. Osim određivanja

polarnosti veze, potrebno je odrediti polarnost petlje. Naime, pošto postoji više mogućih pozitivnih i negativnih veza, polarnost petlje se može odrediti tako što se pomnože znakovi polarnosti pojedinačnih veza u petlji i pronađe neto znak (Lane, 2008, 10).

DUP imaju određene nedostatke poput: nedostatka preciznosti, nedostatka jasne distinkcije između nivoa i stopa, grešaka u određivanju polarnosti petlji itd. (Lane, 2008, 12-14).

Dijagrami nivoa i stopa su detaljniji od dijagrama sa uzročnim petljama. Svaka uzročna petlja mora da sadrži makar jedan nivo. Ako uzročna petlja ne sadrži nivo, ne može se identifikovati ponašanje tokom vremena koje treba ispitati. U dijagramima nivoa i stopa, svaki element je na odgovarajući način predstavljen (Sterman, 2000, 192):

- nivoi su predstavljeni pravougaonima;
- prilivi su reprezentovani strelicama koje "uviru" u nivo;
- odlivi su predstavljeni strelicama koje "izviru" iz nekog nivoa;
- ventili predstavljaju stope;
- oblaci reprezentuju mesta izvorišta, tj. ušća. Izvorište predstavlja nivo iz koga stopa potiče, a ušća predstavljaju nivoe u koje stope ulaze.

Neke greške (poput određivanja polarnosti veza i petlji) mogu se izbeći predstavljanjem feedback petlji pomoću dijagrama nivoa i stopa, zbog toga što su odnosi između komponenata u dijagramu nivoa i stopa striktno definisani, za razliku od dijagrama sa uzročnim petljama. Pošto su generalno kompleksniji i zahtevaju više vremena da se kreiraju, dijagrami nivoa i stopa pružaju mnogo više informacija nego dijagrami sa uzročnim petljama. Shodno tome, oni predstavljaju adekvatnu osnovu za donošenje zaključaka o ponašanju sistema (Lane, 2000, 244). Uprkos tome, postoje i određena ograničenja njihove upotrebe, kao što su: mogu da podstaknu preterano detaljisanje; da budu previše kompleksni i tehnički orijentisani; ne mogu da omoguće dijagramsko objašnjenje za sve tipove fenomena itd. (Lane, 2000, 244; Lane, 2008, 15)

Na osnovu dijagrama sa uzročnim petljama ili dijagrama nivoa i stopa, može se dalje, u fazi formulacije

modela, opredeliti skup odgovarajućih jednačina, tj. razviti odgovarajući matematički model situacije koja je predmet istraživanja. Budući da je vreme jedan od ključnih faktora, potrebno je opredeljivanje sukcesivnog niza stanja sistema tokom vremena i, shodno tome, periodično obračunavanje jednačina. Prema Forrester-u (1972, 74), niz izračunavanja koje treba sprovesti prikazan je na sledećoj slici:

Slika 1 Izračunavanja u trenutku K

Izvor: Forrester, 1972, 74 (Prema: Petrović, 2010, 378)

Osnovne jednačine modela SD podeljene su u dve grupe: jednačine nivoa i jednačine stopa, s tim da se najpre izračunavaju jednačine nivoa (Petrović, 2010, 377-379): Jednačine nivoa pokazuju na koji način odrediti nivoe u trenutku K, zasnovane na nivouima u trenutku J i stopama za interval JK. Jednačine nivoa su nezavisne jedna od druge, a zavise jedino od informacija pre trenutka K. Zato nivo u trenutku K zavisi od: prethodne vrednosti nivoa u trenutku J i stope toka u intervalu JK.

Jednačine stopa se obračunavaju u sadašnjem trenutku K, nakon što se reše jednačine nivoa. Vrednosti određene pomoću jednačina stopa određuju stope koje reprezentuju delovanja koja će biti preduzeta tokom narednog vremenskog intervala KL. Dakle, jednačine stopa determinišu stope toka između nivoa posmatranog sistema. Jednačine stopa izračunavaju

se na osnovu sadašnjih vrednosti nivoa u dotičnom sistemu, s tim što su po pravilu uključeni nivo iz kojeg stopa potiče i nivo u koji stopa ulazi. Stope uzrokuju promene u nivouima. Generalno, jednačine stopa treba posmatati kao instrument kontrolisanja onoga što će se u sistemu desiti u narednom periodu. Međutim, u jednačinama stopa mogu se pojaviti i određene pomoćne varijable kao odgovarajuća podvrsta. Jednačine stopa su nezavisne jedna od druge, a njihove međusobne interakcije se odvijaju preko njihovih budućih efekata na nivo.

Kada se nivo izračuna za trenutak K i stopa za interval KL, vreme se indexira, tj. pomera za jedan vremenski interval nadesno, odnosno na Slici 1 reč je o tome da nivoi u trenutku K postaju nivoi u trenutku J, a stope za interval KL stope intervala JK. Navedeno znači da se trenutak K koji označava sadašnjost pomera za jedan interval dužine DT. Tada se može ponoviti niz izračunavanja da bi se odredilo novo stanje posmatranog sistema u trenutku koji je za jedan interval DT kasniji od trenutka prethodnog stanja. Razvijeni model utvrđuje kretanje dotičnog sistema kroz vreme.

Generalno, nivo se može predstaviti sledećom jednačinom (Sterman, 2000, 194):

$$Nivo(t) = \int_{t_0}^t [Prilivi - Odlivi] ds + Nivo(t_0) \quad (1)$$

pri čemu je nivo određen u trenutku t (trenutak K na Slici 1), a prilivi se određuju u bilo kom trenutku s između početnog vremena t_0 i tekućeg vremena t. Isto tako, neto stopa promena bilo kog nivoa, tj. njen izvod predstavlja razliku između priliva i odliva, definišući određenu diferencijalnu jednačinu:

$$d(Nivo)/dt = Priliv(t) - Odliv(t) \quad (2)$$

Uz jednačine nivoa i stopa, posebnu klasu jednačina u modelu predstavljaju tzv. pomoćne jednačine, odnosno jednačine na koje se razlaže odgovarajuća jednačina stopa u situaciji kada je dotična jednačina stopa izuzetno kompleksna. Za razliku od jednačina nivoa i stopa, pomoćne jednačine moraju biti izračunate u tačno određenom redu. Načelno, pomoćna varijabla

zavisi samo od: nivoa koji su već poznati i drugih pomoćnih varijabli koje se mogu izračunati.

Osim navedenih jednačina, od odgovarajućeg značaja su i jednačine za početne vrednosti, kojima se definišu inicijalne vrednosti svih nivoa i nekih stopa koje se moraju odrediti pre nego što počne izračunavanje jednačina modela, ali se ove jednačine koriste i da bi se izračunale vrednosti nekih konstanti. Rešavanje prezentiranih jednačina sprovodi se pomoću računara, tj. specijalno razvijenih softvera koji se koriste u SD. Kada se formulisani model uvede u kompjuterski softver, potrebno je sprovesti nekoliko preliminarnih simulacionih istraživanja. Odnosno, potrebno je odrediti odgovarajuću vrednost intervala DT i analizirati stabilnost stanja sistema (Petrović, 2010, 382-383):

Pri opredeljivanju vremenskog intervala DT neophodno je voditi računa o odnosu brzine simulacije i tačnosti. Generalno, interval vremena DT određen je najkraćom vremenskom konstantom upotrebljenom u dotičnom modelu. Analiza stabilnosti stanja sistema pruža informacije o pouzdanosti samog modela i stabilnosti modeliranog segmenta realnosti.

Pod testiranjem ili procenom validnosti modela podrazumeva se poređenje modela sa realnošću u cilju prihvatanja ili odbacivanja modela. Zapravo, procena validnosti modela u SD je proces uspostavljanja poverenja u ispravnost i korisnost modela. Reč je o kompleksnom procesu u kojem svako ima sopstvene ciljeve i kriterijume za procenu modela. Pojam validnosti kao ekvivalent za poverenje je u konfliktu sa viđenjem po kojem se validnost izjednačava sa apsolutnom istinom. Poverenje u neki model predstavlja adekvatan kriterijum zato što ne može biti dokaza za apsolutnu ispravnost sa kojom model predstavlja realnost. Validnost je, takođe, relativna u smislu da može biti adekvatno procenjena samo u odnosu na određenu svrhu. Shodno tome, procena validnosti ne može biti u potpunosti objektivna i formalan proces, već mora imati i subjektivne i kvalitativne komponente. Odnosno, procena validnosti modela predstavlja gradacijski proces izgradnje poverenja u modele (Forrester & Senge, 1979, 8; Barlas, 1996, 188).

Postoji veliki broj testova validnosti modela koji se mogu klasifikovati na različite načine. Forrester & Senge (1979) razlikuju sledeće testove:

1. testovi strukture modela (test verifikacije parametara, adekvatnosti granica strukture, test strukture u ekstremnim uslovima i sl.);
2. testovi ponašanja modela (test reprodukovanja ponašanja, test predviđanja ponašanja, test promena ponašanja, itd.);
3. testovi implikacija politike (testovi unapređenja sistema, test predviđanja promene ponašanja, test senzitivnosti politike, itd.).

Barlas (1996, 189) izdvaja sledeće testove validnosti modela u SD: testovi validnosti strukture (u okviru kojih se razlikuju direktni testovi strukture i testovi ponašanja zasnovanih na strukturi) i testovi validnosti ponašanja.

Budući da postoji mnogo testova, postavlja se pitanje o tome o tome da li svi testovi moraju biti sprovedeni. Osim toga, od odgovarajuće je važnosti razmotriti i pitanje o tome kada treba okončati proces procene validnosti modela. U tom smislu, završetak procesa procene validnosti modela zavisi od sledećih determinanti: troškovi procene validnosti, potencijalni stepen validnosti modela, veličina modela, očekivanja klijenata, iskustvo klijenata u modeliranju, relativni značaj, tj. rizik odluke, obim i dostupnost empirijskih podataka i nivo stručnosti modelara (Schwaninger & Groesser, 2012). Uprkos činjenici da neće uvek biti moguće da se sprovedu svi testovi izgradnje poverenja u modele SD, postojanje široke varijetnosti testova ipak povećava verovatnoću da će se sprovesti veći broj testova i da će više ljudi biti uključeno u sveukupan proces procene validnosti. Naime, jedno od ključnih određenja prethodno pomenutih testova je lakoća sprovođenja. Pristupačnost celokupnog procesa testiranja je krucijalna za verovatnoću uspeha modeliranja u SD (Forrester & Senge, 1979, 36; Richardson, 1996, 147).

Poslednja faza u procesu modeliranja je faza implementacije, tj. primene modela u dizajniranju politika. Kada se stekne poverenje u strukturu i ponašanje modela, model se koristi za dizajniranje odgovarajućih politika. Dizajniranje politike je mnogo više od promene vrednosti parametara i uključuje kreiranje potpuno novih strategija, struktura i pravila odlučivanja. Dok feedback struktura sistema determiniše njegovu dinamiku, politike će uključiti

promenu dominantnih feedback petlji redizajniranjem strukture nivoa i stopa, eliminisanjem vremenskog kašnjenja, promenom toka i kvaliteta informacija dostupnih na ključnim tačkama odlučivanja ili fundamentalnim preosmišljavanjem procesa odlučivanja u sistemu (Stermann, 2000, 104). Zapravo, modeli SD mogu biti upotrebljeni za redizajniranje: strukture sistema i/ili politika odlučivanja (Petrović, 2010, 382). Implementacija modela se ne završava sa završetkom nekog određenog projekta ili rešavanjem određenog problema, već se mogu primeniti i za rešavanje nekih drugih, sličnih problema (Stermann, 2000, 81).

ILUSTRACIJA PRIMENE MODELA SISTEMSKE DINAMIKE

Neka je predmet posmatranja preduzeće koje je uvelo nov proizvod na tržište i cilj mu je da istraži proces i predvidi dinamiku prihvatanja novog proizvoda na tržištu. U tom smislu, može biti razvijen odgovarajući

model SD, koji omogućava predviđanje dinamike prihvatanja novog proizvoda na tržištu. F. Bass (1969) opredeljuje preliminarne pretpostavke Modela, koje su dalje razvijene u konceptijskom okviru SD (Morecroft 2007; Sterman, 2000).

Na Slici 2 prikazan je model prihvatanja novog proizvoda i identifikovani su ključni nivoi, stope i feedback petlje. Reč je o modelu koji obuhvata potencijalne korisnike i korisnike imajući u vidu samo usmenu propagandu proizvoda. Model u kome stopa prihvatanja predstavlja rezultat usmene propagande podrazumeva sledeće dve pretpostavke (Bass, 1969): Pre svega, neophodno je da postoje tzv. inicijalni korisnici, tj. vrednost ove varijable u modelu ne sme biti nula, što znači da mora postojati jedan ili više onih koji su već koristili proizvod. Osim toga, pretpostavlja se da se proizvod kupuje samo na osnovu informacija ili preporuka koje se dobiju od postojećih korisnika. Ovakve pretpostavke ograničavaju generalnost modela, što se može otkloniti uvođenjem reklamiranja kao važne determinante procesa prihvatanja novog proizvoda na tržištu.

Slika 2 Ključni nivoi, stope i feedback petlje u procesu prihvatanja novog proizvoda na tržištu

Izvor: Morecroft, 2007, 167

U modelu postoje dva ključna nivoa (Sterman, 2000, 324-325): korisnici i potencijalni korisnici, a stopa prihvatanja proizvoda izjednačena je sa stopom prihvatanja na osnovu usmene propagande. Takođe, postoje dve feedback petlje - jedna je pozitivna ili pojačavajuća, koja je predstavljena usmenom propagandom, a druga negativna ili uravnotežujuća predstavljena zasićenošću tržišta. Pozitivna petlja pokazuje da što je više korisnika, više je onih koji usmeno mogu da propagiraju proizvod. Ova petlja, najpre, dominira sistemom, produkujući rast. Nasuprot tome, negativna petlja usporava sistem, s obzirom na to da broj potencijalnih korisnika opada, jer raste zasićenost tržišta (budući da svaki novi korisnik potiče iz kategorije potencijalnih korisnika). Cilj je da nivo potencijalnih korisnika postane nula, tj. da se svi potencijalni korisnici transformišu u korisnike proizvoda.

Pretpostavka je da se ukupna populacija (tj. potencijalno tržište proizvoda) sastoji od milion ljudi, koji povremeno razgovaraju o svojim kupovinama. Ovakva sklonost ljudi označena je kroz stopu kontakata čija je pretpostavljena vrednost 100. Broj godišnjih kontakata korisnika sa ostatkom populacije predstavlja proizvod stope kontakata i korisnika. Neki od ovih kontakata dovodi do prihvatanja proizvoda (dok susret dva korisnika ne može da dovede do prihvatanja). Verovatnoća da je bilo koji slučajno izabrani kontakt zapravo kontakt između korisnika i potencijalnog korisnika jednaka je udelu potencijalnih korisnika u ukupnoj populaciji. Ovaj odnos opada kako se proces prihvatanja nastavlja, dostižući nulu kada je tržište potpuno zasićeno. Takođe, neće svaki kontakt između korisnika i potencijalnih korisnika rezultirati prihvatanjem proizvoda. Udeo uspešnih kontakata naziva se udeo prihvatanja, čija je pretpostavljena vrednost 0.02, što znači da 2% kontakata dovodi do prihvatanja proizvoda. Stopa kontakata i udeo prihvatanja opredeljuju usmenu propagandu.

U modelu je vreme označeno u godinama, a dt predstavlja dovoljno mali trenutak da obezbedi numeričku tačnost. Broj korisnika u datom trenutku vremena jednak je zbiru prethodnog broja korisnika u vremenu $(t-1)$ i stope prihvatanja u intervalu dt . Nasuprot tome, broj potencijalnih korisnika u vremenu t je jednak razlici između prethodnog broja korisnika

(tj. broja korisnika u vremenu $t-dt$) i stope prihvatanja u tom intervalu. Smatra se da inicijalno postoji 10 korisnika od milion u ukupnoj populaciji, tako da preostali broj ljudi predstavlja potencijalne korisnike. Stopa prihvatanja se izjednačava sa prihvatanjem na osnovu usmene propagande.

Ako se navedene varijable označe na sledeći način:

KP - korisnici proizvoda

SP - stopa prihvatanja

PK - potencijalni korisnici

IPK - inicijalni potencijalni korisnici

PUP - prihvatanje na osnovu usmene propagande

SK - stopa kontakata

UP - udeo prihvatanja

UPP - ukupna populacija

mogu se opredeliti sledeće jednačine (Morrecroft, 2007, 168-169):

$$KP(t) = KP(t - dt) + (SP) \cdot dt \quad (3)$$

$$PK(t) = PK(t - dt) - (SP) \cdot dt \quad (4)$$

$$IPK = UPP - KP \quad (5)$$

$$SP = PUP \quad (6)$$

$$PUP = SK \cdot KP \cdot \frac{PK}{UPP} \cdot UP \quad (7)$$

Dinamika prihvatanja novog proizvoda na osnovu usmene propagande prikazana je na Slici 3, gde se može uočiti da inicijalno postoji samo 10 korisnika, koji počinju da prenose svoja iskustva, tj. da propagiraju proizvod. U prvih pet godina korisnici i njihovi sledbenici imaju veoma mali uticaj na preostali deo potencijalnih korisnika koji još nisu čuli za proizvod. Shodno tome, u određenom periodu vremena stopa prihvatanja je blizu nule, mada postoji određeni rast

koji je relativno mali u odnosu na ukupnu populaciju od milion ljudi. Tokom četvrte godine broj korisnika počinje da raste. Dakle, najveći deo ukupne populacije postaje korisnik proizvoda u intervalu između 5. i 8. godine od uvođenja proizvoda na tržište. Nakon toga stopa prihvatanja počinje da opada pošto raste zasićenost tržišta.

Ako bi broj inicijalnih korisnika bio nula, čak i sa milion potencijalnih korisnika, rast uopšte ne bi postojao, pošto je proizvod nepoznat. Navedeno ukazuje na potrebu za postojanjem inicijalnih korisnika da bi se uopšte otpočelo sa usmenom propagandom, što predstavlja ključnu pretpostavku modela. Da bi se stvorila takva baza inicijalnih korisnika, potrebno je uključiti još neke elemente promocije poput reklamiranja proizvoda. U

tom smislu, ovaj model može da se proširi uvođenjem reklama i praćenjem njihovih efekata na prihvatanje proizvoda (Morecroft, 2007, 171).

Budući da se modeli SD mogu primeniti na bilo koji dinamički sistem, postoji veliki broj studija slučajeva i primera njihovog uspešnog korišćenja (Forrester, 1972; Sterman, 2000; Morecroft, 2007)

KVALITATIVNO I GRUPNO MODELIRANJE U SISTEMSKOJ DINAMICI

U rešavanju upravljačkih problema SD poseduje određene prednosti: Snaga SD počiva, pre svega, u pretpostavci da je struktura ključna determinanta

Slika 3 Dinamika prihvatanja novog proizvoda na tržištu na osnovu usmene propagande

Izvor: Morecroft, 2007, 170

ponašanja sistema, a da se struktura može predstaviti odgovarajućim pozitivnim i negativnim feedback petljama. Razumevanje feedback struktura može da pomogne menadžerima da bolje upravljaju kompleksnošću i da obezbede efikasnije odluke kojima će ostvariti svoje ciljeve. Budući da modeli SD ističu ključne tačke odlučivanja i da su akcije donosilaca odluka uključene u modele, mogu se utvrditi posledice tekućih politika i istražiti alternativne strategije (Jackson, 2003, 78).

Međutim, kritičari smatraju da su modeli SD neprecizni i nedovoljno rigorozni, tj. da se modeli često grade ignorišući određene teorije u području koje se istražuje ili se grade bez dovoljno prikupljenih podataka. Ako su modeli SD neprecizni, onda oni ne mogu obezbediti tačna predviđanja budućih stanja sistema i, samim tim, biće od ograničene korisnosti donosiocima odluka (Jackson, 2003, 79-80).

Takođe, Richardson (1996) kao neke od ključnih problema u daljem razvoju SD ističe: razumevanje ponašanja modela, validnost modela, unapređenje praktične primene modela, pristupačnost i dostupnost modela, kvalitativno naspram kvantitativnog modeliranja, tj. identifikovanje uslova u kojima je bolje upotrebiti određene kvalitativne instrumente, kao i uslova koji zahtevaju formalno, kvantitativno modeliranje, itd.

SD je dugo bila bazirana isključivo na izgradnji kvantitativnih modela. Iako su modeli SD matematičke reprezentacije problema i alternativa politike, većina dostupnih informacija nije po svojoj prirodi numerička, već kvalitativna. Upkos tome što postoji generalno slaganje o važnosti kvalitativnih podataka i instrumenata tokom razvoja modela SD, ne postoji jasan opis toga kako i kada ih treba koristiti.

Nedostatak integrisanog skupa procedura da bi se dobila i analizirala kvalitativna informacija stvara jaz između modeliranog problema i modela problema. Ovaj jaz je još uočljiviji kada model podrazumeva upotrebu soft varijabli, poput satisfakcije potrošača ili kvaliteta proizvoda. Problemi povezani sa kvantifikacijom i formulacijom kvalitativnih varijabli doveli su do razvoja tzv. kvalitativne SD (Coyle, 2000; Homer & Oliva, 2001; Luna Reyes & Andersen, 2003; Dhawan et al., 2011). U tom smislu, mogu se koristiti određeni

dijagrami poput dijagrama sa uzročnim petljama, kao kvalitativni instrumenti na osnovu kojih se, bez kvantifikacije i simulacije, mogu izvoditi zaključci o politici (Coyle, 2000, 233).

Međutim, postavlja se pitanje o tome da li određene kvalitativne instrumente treba koristiti bez ili sa dodatnom kvantifikacijom i simulacijom. Iako postoje situacije u kojima se kvalitativni instrumenti koriste bez dodatne kvantifikacije i simulacije, smatra se da je simulacija skoro uvek poželjna u analizi politike, čak i kada postoje određene neizvesnosti i soft varijable. Zapravo, potrebno je razumeti da postoje opasnosti od zaključaka koji se donose samo na osnovu kvalitativnih instrumenata, kao i ograničenja simulacionih modela (Homer & Oliva, 2001). Neka istraživanja o efektima kvantitativnog i kvalitativnog modeliranja u SD pokazuju da je za relativno jednostavne probleme reprezentovane jednostavnim dijagramima dovoljno koristiti instrumente kvalitativnog modeliranja u SD. Međutim, za kompleksne zadatke potrebno je uključiti kvantitativne modele i simulaciju (Dhawan et al., 2011, 321). Upkos tome što je kvantifikacija korisna, treba biti obazriv kada se pokušavaju kvantifikovati soft varijable. Reč je o području istraživanja koje je izuzetno važno za dalji razvoj SD (Coyle, 2001, 362).

Dakle, može se zaključiti da nije adekvatno pitanje o tome da li se koriste kvalitativni podaci i instrumenti u SD, već kada i kako se koriste. Iako pojedini autori smatraju da značaj kvalitativnih podataka najviše dolazi do izražaja u fazi konceptualizacije, a najmanje u fazi formulisanja modela, kvalitativni podaci su prisutni u svim fazama procesa modeliranja (Luna-Reyes & Andersen, 2003, 275). Shodno tome, mogu se identifikovati neke od ključnih tehnika prikupljanja kvalitativnih podataka u svakoj fazi modeliranja, poput intervju, Delfi tehnike, nominalne grupne tehnike i slično (Luna-Reyes & Andersen, 2003, 287-292).

Drugi vid kritika u SD povezan je sa unitarnom prirodom upravljačkih problemskih situacija kojima je primerena, odnosno sa funkcionalističkom sistemskom paradigmom na kojoj je SD utemeljena. Naime, problemske situacije u organizacijama predstavljaju određene subjektivne konstrukcije i interpretacije participanata, zbog čega identifikovanje odgovarajućih struktura podrazumeva kontinuirani

proces pregovaranja između participanata tj. klijenata u procesu modeliranja. U datom kontekstu, težnja SD da sistem istraži objektivno, izvan sistema, pomoću modela izgrađenim na feedback procesu, predstavlja izuzetno složen zadatak. Takođe, u SD se polazi od činjenice da postoji saglasnost oko svrhe modela i time se zanemaruje varijetetnost svrha i ciljeva koje različiti participanti imaju u rešavanju upravljačkih problema (Jackson, 2003, 81).

Kao odgovor na ovakve kritike nastaje tzv. grupno modeliranje (Vennix et al. 1995; Vennix, 1999; Rouwette et al. 2001) ili participativno modeliranje (Lane, 2010), kojim se pokušava da se u proces izgradnje modela uključe različite percepcije, vrednosti i mišljenja participanata, tj. klijenata. Reč je, zapravo, o pokušaju da se SD primeni i na neke nedovoljno dobro definisane, tj. nestrukturirane probleme i tako približi interpretativnoj paradigmi. U istraživanju efektivnosti grupnog modeliranja u nestrukturiranim problemskim situacijama od relevantne važnosti je istražiti određena kognitivna ograničenja, tj. načine na koje se može povećati kapacitet grupnog procesiranja informacija, s jedne strane, i načina na koji participanti uočavaju i interpretiraju različite problemske situacije (Vennix, 1999, 381).

Da bi se efektivno suočili sa nestrukturiranim problemima, predstavnici SD treba, pre svega, da prihvate činjenicu da u mnogim situacijama nije korisno ili je čak nemoguće sprovesti sve faze procesa modeliranja. Kao što je već istaknuto, u nekim situacijama je bolje primeniti samo određene kvalitativne instrumente bez kvantifikacije i simulacije (Coyle, 2000; Dhawan et al., 2011). Zapravo, potrebno je pažljivo proceniti uslove i efekte upotrebe kvalitativnog i kvantitativnog modeliranja.

Osim navedenog, potrebno je istražiti različite načine podsticanja timskog učenja i efektivne komunikacije u grupama kako bi se unapredio proces modeliranja. Da bi se obezbedilo učenje, participanti moraju da postanu modelari. Odnosno, da bi se omogućilo efektivno učenje iz modela, potrebno je da participanti aktivno učestvuju u razvoju modela. Generalno, u proceni efektivnosti grupnog modeliranja, može se zaključiti da se participiranjem u procesu modeliranja povećava posvećenost klijenata i olakšava implementacija (Rouwette et al., 2001, 32, Vennix et al., 1995, 55).

Međutim, nastojanjem da se približi interpretativnoj paradigmi, SD rizikuje da izgubi svoje ključno funkcionalističko određenje da identifikuje zakonitosti upravljanja ponašanjem sistema. To znači da SD, pre svega, treba da zadrži svoje funkcionalističke karakteristike (Jackson, 2003, 81). Naime, određena znanja i veštine potrebne za izgradnju modela u SD treba kombinovati sa odgovarajućim veštinama i znanjima potrebnim za olakšavanje participacije i pregovaranja u grupama (Vennix, 1999, 392).

Određene manjkavosti SD mogu da se prevaziđu kombinovanim korišćenjem SD i nekih interpretativnih sistemskih pristupa, poput Metodologije soft sistema (Coyle & Alexander, 1996; Lane & Oliva 1998; Rodríguez Ulloa & Paucar-Caceras, 2005). Osim toga, SD se može kombinovati i s nekim drugim funkcionalističkim prilazima kao što je Organizaciona kibernetika (Schwaninger, 2004; Schwaninger & Pérez Ríos, 2008).

ZAKLJUČAK

SD, kao relevantna strukturalističko-funkcionalistička sistemska metodologija, oslonjena na teoriju informacionog feedback-a i kontrole, primerena je rešavanju kompleksno-unitarnih upravljačkih problema, tj. problemskih situacija. Upravljačke problemske situacije u SD iskazane su feedback strukturom i procesima unutar nje, reprezentovanim odgovarajućim dijagramima i matematičkim modelima sistema.

Modeli SD predstavljaju izuzetno moćan instrument rešavanja upravljačkih problema u organizacijama. Razvijeni kroz odgovarajući proces modeliranja, modeli SD mogu biti upotrebljeni u (re)dizajniranju odgovarajućih organizacionih politika i/ili struktura. Sam proces modeliranja je izuzetno složen, iterativan postupak kretanja modelara kroz određene faze. Iako postoje različite klasifikacije faza procesa modeliranja, generalno se mogu izdvojiti sledeće: faza konceptualizacije, tj. identifikovanja problema i njegovog predstavljanja feedback petljama; faza formulisanja, tj. faza izgradnje matematičkog modela reprezentovanog odgovarajućim jednačinama nivoa i stopa; faza testiranja ili procena validnosti modela njegovim poređenjem sa realnim svetom i faza implementacije, tj. primene modela u dizajniranju

politika za poboljšanje rezultata funkcionisanja organizacije.

Izgrađeni na pretpostavci da struktura generiše određeno ponašanje, modeli SD, kroz kompjuterske simulacije, omogućavaju predviđanje budućeg ponašanja sistema, što je pokazano i na primeru prihvatanja novog proizvoda na tržištu. Zapravo, istraživanjem teorijsko-metodoloških i aplikativnih aspekata modeliranja upravljačkih problema u konceptijskom okviru SD, može se potvrditi ključna hipoteza u radu.

Uprkos velikom broju uspešnih primena modela SD u rešavanju upravljačkih problema, modeli SD poseduju određena ograničenja. Reč je, pre svega, o različitim problemima povezanim sa kvantifikacijom određenih soft varijabli i mogućim nepreciznostima i greškama koje iz toga proizilaze. Kao odziv na ove manjkavosti nastaje tzv. kvalitativna SD ili kvalitativno modeliranje u SD, koje ističe značaj samostalne i/ili kombinovane upotrebe određenih kvalitativnih i kvantitativnih instrumenata u SD. Takođe, treba istaći i ograničenja povezana sa funkcionalističkom paradigmom na kojoj je SD zasnovana. Navedeno se odnosi na činjenicu da SD pretpostavlja postojanje saglasnosti oko svrhe modela, čime zanemaruje različite percepcije i intepretacije participanata, tj. klijenta uključenih u proces modeliranja. U tom smislu, postoje težnje da se kroz tzv. grupno modeliranje SD približi interpretativnoj paradigmi. Uprkos tome što je u istraživanje potrebno uključiti određene soft varijable i percepcije participanata, SD ne bi trebalo da izgubi svoja ključna strukturalističko-funkcionalistička određenja u nastojanjima da se približi interpretativnoj paradigmi.

Vodeći računa o identifikovanim manjkavostima SD i njenih modela, potrebno je istražiti različite pretpostavke, uslove, načine i domete kombinovanog korišćenja SD i drugih sistemskih pristupa menadžmentu. SD se može kombinovano koristiti sa odgovarajućim intepretativnim sistemskim metodologijama poput Metodologije soft sistema (MSS), pri čemu modeli SD predstavljaju odgovarajuću podršku instrumentima MSS-a u istraživanju strukture i funkcionisanja organizacija. Osim toga, SD se može kombinovati sa sistemskim prilazima koji, takođe, pripadaju funkcionalističkoj sistemskoj paradigmi,

kao što je Organizaciona kibernetika. Kombinovano korišćenje SD, tj. njenih modela sa drugim metodologijama, metodima i tehnikama predstavlja posebno područje relevantno za buduća istraživanja.

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Review paper

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SYSTEM DYNAMICS MODELS IN MANAGEMENT PROBLEMS SOLVING

Dejana Zlatanovic*

The models represent the key methodological tool for management problems solving in System Dynamics (SD) as a functionalist systems methodology. Above all, it is about mathematical models, built according to appropriate feedback structures, i.e. specific elements and flows that form feedback loops. Since SD is based on the assumption that a system structure represents the behavioral key determinant, SD models provide an effective prediction of the future system behavior. The paper focuses on the modeling process in SD, as a complex, iterative process, consisting of the following phases: model conceptualization, formulation, testing and implementation. Although being extremely useful in solving numerous organizational managing problems, SD models have certain disadvantages as a consequence of their quantitative nature. Qualitative modeling and group model-building, as possible directions for further SD development, are appropriately important in SD models' deficiencies elimination.

Keywords: System Dynamics, modeling process, System Dynamics models, management problems solving

JEL Classification: M10

INTRODUCTION

Different systems approaches and methodologies can be applied in researching and solving contemporary management problems. System Dynamics (SD), as a relevant systems methodology, is appropriate for management problem situations characterized as complex and unitary. According to this, and bearing in mind the SD key determination – focused on researching the feedback structure generating a certain system behavior – SD represents relevant structuralist-

functionalist systems approach to management. The basic allegations of the management problem situations in SD are the structure and processes within SD, and the key tools in management problems solving are appropriately developed models. In that sense, the research will be focused on the SD modeling process, i.e. SD models as relevant tools for management problems solving within contemporary organizations.

The aim of the paper is to demonstrate SD possibilities, i.e. its models, in dealing and solving contemporary management problems. In fact, the aim is to demonstrate the ways in which SD can help managers move through adequate problem areas in predicting a future behavior and designing certain policies for an improvement in organizational functioning.

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This paper is based on the following key hypothesis: If the structure represents the key determinant of a system behavior, then SD models – through appropriate computer stimulations – provide a prediction of a future behavior for the researched system.

First of all, the paper introduces the key SD features as a functionalist systems approach to management. Then, the process of SD modeling is researched, i.e. certain characteristics and modeling process phases are specified. Since the focus is on the modeling process itself, each phase is considered separately – conceptualization, formulation, testing and implementation. The SD model is briefly illustrated in the paper on an example of a new product adoption on the market, because this is about tools with an exceptional applicative potential. Finally, some deficiencies of SD models are identified, as well as possible directions for further SD development through qualitative modeling and group model-building.

SYSTEM DYNAMICS – A FUNCTIONALIST SYSTEMS APPROACH TO MANAGEMENT

System Dynamics, as a systems approach to management problems solving, is based on the theory of information feedback and control. SD focus is on the problems that can be modeled as systems, essentially made of different elements and flows, i.e. inter-elementary relations that create a feedback loop and are represented as continual processes. Appropriate deterministic model structures not evolving over time are developed for those systems. SD modeling and simulation are widely used in the field of social, and especially economic, systems and different types of organizations, with a significant stress on the policy and design analysis.

J. W. Forrester (1972) made foundations of SD, originally entitled as Industrial Dynamics. SD deals with time changeable interactions of different parts of the management system in order to determine in which way the organizational structure, policy, time delay in making decisions and actions interact affecting the system's success.

Since management problem situations are represented by appropriate structures and processes within, the

theoretical base of SD is as follows (Petrović, 2010, 369): A system's behavior is primarily conditioned by its structure. It is supposed that the considered structure and processes can be represented by adequate diagrams and mathematical models of system. According to the SD theory, a lot of variables of the existing complex systems become casually connected in corresponding feedback loops. System connections between feedback loops constitute the system's structure, and that structure is the key determinant of the system's behavior. (Jackson, 2003, 67).

As an essential SD aggregate, a structure is determined by (Petrović, 2010, 370-371): line, feedback direction, nonlinearity and loop multiplicity. The number of levels, i.e. number of variables used for representing the structure of the researched system, determines the system line. Feedback can be positive and negative, considering the direction. Positive feedback causes an increase, i.e. creates a rise or a fall, and the negative one means a specific preventing or controlling influence. The nonlinear connecting of positive and negative loops can lead to loop domination, allowing controlled growth. Management problem situations are, as a rule, represented by structures with multiple positive and negative loops. It is assumed that an effective prediction and control can be made and conducted, respectively, by specified structure characteristics. Time-based mathematic SD models simulate possible scenarios of an organization's functioning, and, in that way, provide relevant trends projections. Starting with the fact that a concrete prediction is reliable, the focus is accordingly transferred to introducing appropriate control policies.

Beside SD prediction and control, the SD model is of a great importance, and its basic aggregates are levels and rates. The level is considered to be a changeable value over time. In other words, levels are the present variable values, i.e. values that have resulted from an accumulated difference between inflows and outflows (Forrester, 1972, 68). Apart from levels, rates define the present flows among a system's levels. Rates correspond to an activity, while levels measure the resulting state which the system has been brought to by the activity. For example, the number of employees represents the level determined by the hire rate and the quit rate; or the debt level is determined by the borrowing rate and the repayment rate, etc. (Stermann, 2000, 200).

The mathematical expression of the SD model is represented by a system of equations (levels and rates equations) controlling variable interactions of the considered problem situation that change over time. Since the modeled system moves over time, from time to time it is necessary that equations be converted. Different pieces of software, such as: DYNAMO, Powerism, Venism, have been developed to support SD modeling and simulation.

THE MODELING PROCESS IN SYSTEM DYNAMICS

Modeling, as an integral part of the learning process in organizations, represents an iterative, continual process of the formulating, testing and revision of both formal and mental models. As an adequate expression of management problem situations, the models are a powerful tool for identifying and representing their key determinations, ways they are manifested and their relevant implications. According to that, valid models are an extremely useful methodological tool in organization management, i.e. in deciding on the way a manager should go through management problem areas in contemporary organizations (Petrović, 2010, 572). The aim of the SD model is to identify policies and organizational structures that improve functioning and provide an organizational success.

The modeling process should be focused on important questions, such as essential organizational problems, and is part of the organizational and social contexts. Before the modeling process starts, the modeler must have access to the organization and identify clients. That is about individuals and groups whose behavior is affected by the modeling process, i.e. whose behavior has to be changed in order to solve the problem. The modeling process should be consistent with clients' skills, abilities and aims. Most clients are interested in the fact that models should support conclusions already made, or use them as power tools inside the organization. However, the modeler must be prepared to inform clients about their wrong assumptions, if the modeling process says so (Sterman, 2000, 84-85).

The SD model should have the following characteristics, namely, it should be (Forrester, 1972, 67):

- able to describe any problem in cause-effect relations;
- mathematically expressed in a relatively simple way;
- able to include numerous variables, within practical computer ability limits;
- able to manage different discontinuities, not affecting the results, but generate discontinued changes in decisions when necessary.

SD modeling is a process carried out through several phases, and authors classify it in different ways.

Luna-Reyes & Andersen (2003, 275) specify the modeling process phases according to various authors. In that sense, there are following classifications: conceptualization, formulation, testing and implementation; then: problem definition, system conceptualization, model formulation, analysis of model behavior, policy analysis and model use; or: diagram constructing and analysis, simulation phase (stage 1) and simulation phase (stage 2).

Also, Sterman (2000, 86) classifies the modeling process phases into: problem articulation, dynamic hypothesis formulation, simulating model formulation, model testing and policy formulation and implementation.

In spite of different classifications of certain phases, generally, the modeling process includes the following activities (Jackson, 2003, 68-69): Above all, the conceptualization phase, clarifying the problem and identifying variables having an influence on it. Then, the feedback loop model revealing relations among variables is built. That model, in the formulating phase, further develops into an appropriate mathematical model, i.e. level and rate equations. Those equations, helped by a certain piece of software, provide a relevant computer simulation of a system behavior. The model validity is estimated in the testing phase, and possible ways for improving the results for the system functioning, i.e. certain policy designing, are identified in the implementation phase.

The aim of the conceptualization phase is to build a conceptual model representing a relevant problem within the system. It is necessary that the following activities be conducted in this phase (Albin, 1997, 6):

- the definition of the model purpose;
- the determination of the model boundaries and identification of its key variables;
- the description of the model behavior, i.e. building the reference mode of the key variables;
- the presentation of the system feedback loops by diagrams.

The most important step in the modeling process is problem defining, i.e. setting the model purpose. Each model is the representation of a certain system. In order to be useful, a model should deal with a specific problem and simplify rather than reflect the system in details. The system usefulness lies in the fact that they simplify reality by creating a representation of something that can be understood (Stermann, 2000, 89). The modeler should also consider who the model is primarily designed for. Reaching agreement on the model purpose is of an essential importance. It is very difficult to decide which system components are important without a clear and strictly defined purpose. If the purpose is defined too widely or too abstractly, the model will include too many components and will be too complex for any practical analysis.

The most common mistakes in defining the model purpose are (Albin, 1997, 9):

- the purpose does not enable system understanding;
- the purpose does not reveal policies to improve the system behavior;
- the purpose does not reflect mental models and is not used as a communication and unification tool.

After having chosen the problematic focus field, the modeler must collect relevant data and define the model. When talking about the model boundaries, it is necessary that the fact that every feedback system has closed boundaries which are a frame for generating a certain analyzed behavior be stated. Above all, the modeler has to explore all components considered to be necessary for the system model. It is about the initial components list. In order to specify the model boundaries furthermore, the modeler must divide the initial components list into two important groups (Albin, 1997, 10; Stermann, 2000, 97):

- endogenous – dynamic variables included in the feedback loops of the system, and
- exogenous – components whose values do not directly affect the system.

After dividing these two groups of components, it is necessary that we determine which components are stocks and which are flows. It should be marked that exogenous components can be neither stocks nor flows, but adequate constants (Albin, 1997, 11). The endogenous phenomenon explanation is something that is tended to within the SD, as well as that a problem should be described dynamically, i.e. as an appropriate kind of behavior, developed over time. The time interval should be determined in a way that it can include enough information about the past in order to show the reasons for the occurrence of the problem and describe its symptoms. Also, it should include relevant information about the future to include the delayed and indirect effects of potential policies. The most significant difficulty in mental models is a tendency to think of causes and effects as local and current. In dynamic, complex systems, the cause and effect are distant over time and space, which considers feedback systems to be the ones with long delays, distant from the decision point or the problem symptom (Stermann, 2000, 91).

The reference mode, i.e. a set of diagrams showing the way a problem occurs and how it can evolve in the future, is built after determining the model boundaries and time interval. The reference mode, in fact, represents the key variables behavior over time and can be useful before and after the model building. Reference modes can be changed during the modeling process, and, according to the initial reference mode, the modeler can reassess and redefine the model purpose.

The last step in the conceptualization phase represents the feedback system structure. SD uses different types of diagrams in representing feedback structures. Those are causal loop diagrams, stock and flow diagrams, structure diagrams and policy structure diagrams (Lane, 2008, 9). This paper briefly considers causal loop diagrams and stock and flow diagrams, as the most commonly used tools for the diagram-based representation of a system structure in SD.

Causal Loop Diagrams (CLD) show, above all, the orientation of feedback, as well as the key elements, i.e. variables, and their mutual interaction. Variables are connected by causal links, represented by adequate arrows. Relations that produce change in the same direction (rising or falling) are marked with a positive sign in the causal loop diagram. The positive feedback link means that if the cause increases, the effect also increases above what it would otherwise have been. Also, if the cause decreases, the effect decreases below what it would otherwise have been. Opposite to that, the negative feedback link means that if the cause increases, the effect decreases below what it would otherwise have been; and if the cause decreases, the effect increases above what it would otherwise have been (Sterman, 2000, 139).

Therefore, each link is characterized by a certain polarity, i.e. by the effect direction which the influencing variable has on the influenced variable (Lane, 2008, 5). This describes the structure of the system, not behavior of the variables. Also, this describes something that would happen if a change occurred, not something that really happens. The previously stated expression below or above what it would otherwise have been, has an important significance because an increase or a decrease in the causal variable does not necessarily mean the effect will actually increase or decrease. Beside determining the link polarity, it is necessary that loop polarity be determined. Since there are more possible positive and negative links, the loop polarity can be determined by multiplying the signs of the link polarities in a loop and finding the net sign (Lane, 2008, 10).

CLD have certain deficiencies, such as: a lack of precision, a lack of distinctions between stocks and flows, mistakes in determining the loop polarity, etc. (Lane, 2008, 12-14).

Stock and flow diagrams are more detailed than causal loop diagrams. Each causal loop has to contain at least one level. If a causal loop does not contain a level, the behavior over time that should be examined cannot be identified. Each element is represented adequately in stock and flow diagrams (Sterman, 2000, 192):

- stocks are represented by rectangles;

- inflows are represented by arrows that flow into" the stock;
- outflows are presented by arrows that "rise" from certain stock;
- valves represent flows;
- clouds represent the sources or sinks for the flows. The source represents the stock which the flow arises from, and sinks represent the stocks which the flows "flow into".

Some mistakes (such as determining the link and loop polarity) can be avoided by presenting feedback loops in stock and flow diagrams; therefore, relations among components in stock and flow diagrams are strictly defined, contrary to causal loop diagrams. Being generally more complex and more time demanding to create, stock and flow diagrams provide much more information than causal loop diagrams. According to that, they are an adequate base for making conclusions about the system behavior (Lane, 2000, 244). However, there are certain limits for their use: they can encourage excessive detailing; be too complex and technically oriented; cannot enable a diagram explanation for all types of phenomena, etc. (Lane, 2000, 244; Lane, 2008, 15).

According to causal loop diagrams and stock and flow diagrams, it is possible to determine a set of equations in the model formulation phase, i.e. develop an adequate mathematical model of the situation which is being researched. Due to the fact that time is one of the key factors, it is necessary to determine the successive series of the system's state over time, and consequently a periodically converted equation. According to Forrester (1972, 74), a series of calculations that should be done is presented in the Figure 1.

The basic equations of the SD model are divided into two groups: level equations and rate equations; however, level equations are calculated first (Petrović, 2010, 377-379): Level equations show the ways for determining levels in time K, based on the levels in time J and on rates over the interval JK. Level equations are independent of each other, and only depend on information before time K. That is why the level in time K depends on: the previous level value in time J and the rate in the time JK.

Figure 1 Calculations in time K

Source: Forrester, 1972, 74 (According to: Petrović, 2010, 378)

Rate equations are converted at the present time K, after level equations have been calculated. The values having been determined by rate equations determine the rates that represent actions which will be taken in the following KL time interval. Therefore, rate equations determine flows among the levels of the observed system. Rate equations are calculated according to the present level values in the system, and the starting level and the "flow-into" level are included as a rule. Rates cause level changes. Generally, rate equations should be observed as a control tool of what will happen within the system in the forthcoming period. However, certain auxiliary variables, as an appropriate subgroup, can appear within rate equations. Rate equations are independent one of another, and their mutual interaction is done through their future effects on the levels.

Time is indexed, i.e. moved to the right for one time interval, when the level is calculated for time K and rate for the KL interval, i. e. in Figure 1, levels in time K become levels in time J, and rates for interval KL, rates for the JK interval. This means that time K, representing the present, moves by one DT length interval. Then, a set of calculations can be repeated in order to determine a new state of the observed system in the time which is for one DT interval later than the time from the previous state. The developed model determines the movement of the system throughout

time. Generally, a level, i. e. stock, can be presented by the following equation (Sterman, 2000, 194):

$$Stock(t) = \int_{t_0}^t [Inflows - Outflows] ds + Stock(t_0) \quad (1)$$

where stock is determined in time t (time K in Figure 1) and inflows are determined at any moment between the starting time t_0 and the current time t. The same way, the net flow of change of any stock, i.e. its derivative, represents a difference between the inflow and outflow, defining a certain differential equation:

$$d(Stock)/dt = Inflow(t) - Outflow(t) \quad (2)$$

Beside level and rate equations, the so-called auxiliary equations, i.e. equations decomposed from an appropriate level equation in a situation when a level equation is extremely complex, represent a separate class of equations in the model. Contrary to level and rate equations, auxiliary equations have to be calculated in a precisely determined order. In principle, auxiliary variable depends only on: already known levels and auxiliary variables that can be calculated.

Apart from the stated equations, equations for the starting values are significant. They define the initial values of all levels and some rates that have to be determined before the calculation of model equations starts; however, these equations are used to calculate the values of some constants. Converting the presented equations is done by computer, i.e. specially developed software used in SD. When the formulated model enters computer software, it is necessary that several preliminary simulation researches be done. It is necessary that an appropriate value of the DT interval be determined and the system state stability analyzed. (Petrović, 2010, 382-383):

When determining DT time interval, it is necessary that attention be paid to the relation between the stimulation speed and accuracy. Generally, the DT time interval is determined by the shortest time constant used in the model. The state stability analysis of the system gives information about the reliability of the model itself or the stability of the modeled reality segment.

Testing or the model validation is considered to be a comparison of the model to the reality in order to accept or reject the model. In fact, validation in SD is a process of establishing confidence in the model correctness and usefulness. This is about a complex process, where everybody has their own aims and criteria for the model validity. The idea of validity as an equivalent for confidence is in conflict with the understanding of validity equally as an absolute truth. Confidence in some model is an adequate criterion because there are no proofs for absolute correctness that a model represents reality. Validity is also relative in a sense that it can only be properly assessed for a particular purpose. According to that, validation cannot be a completely objective and formal process, but must have subjective and qualitative components. In other words, model validation is a gradual process of establishing confidence in models (Forrester & Senge, 1979, 8; Barlas, 1996, 188).

There are a great number of tests for model validity that can be classified in different ways. Forrester & Senge (1979) find following tests:

1. tests of model structure (parameter verification test, boundary-adequacy structure test, extreme-conditions test, etc.);
2. tests of model behavior (behavior-reproduction test, behavior prediction test, change-behavior test, etc.);
3. tests of policy implications (system-improvement tests, changed-behavior-prediction tests, policy-sensitivity tests, etc.).

Barlas (1996, 189) singles out the following validity model tests in SD: structure validity tests (direct structure tests and structure-oriented behavior tests) and behavior validity tests.

Since there are many tests, there is a question if all tests have to be used. Besides, it is important that the question when to end the model validation process be considered. In that sense, ending the model validation process depends on the following determinants: the costs of validation, a potential degree of model validity, the model size, clients' expectations and clients' experience with modeling, relative importance, i.e. risk of decision, data intensity and availability and the modeler's level of expertise (Schwaninger & Groesser,

2012). In spite of the fact that it will not always be possible to use all the tests for establishing confidence in the SD models, a wide range of tests increase a probability for using a greater number of tests and including more people into the whole process of model validation. Thus, one of the key determinations of the previously mentioned tests is the easiness of implementation. The accessibility of the whole testing process is crucial for the probability of a modeling success in SD (Forrester & Senge, 1979, 36; Richardson, 1996, 147).

The last phase in the modeling process is the implementation phase, i.e. models application in policy designing. Once trust into the structure and model behavior has been established, the model is used for designing appropriate policies. Designing policies is much more than changing the parameters value, and includes creating completely new strategies, structures and decision rules. While the feedback system structure determines its dynamics, policies will include change of dominant feedback loops by the redesigning of stocks and flows structures; by eliminating the time delay; by change of flow and quality of information available at the key decision points; or by fundamental reformulating the decision-making process within the system (Sterman, 2000, 104). In fact, SD models can be used for redesigning: system structures and/or decision policies (Petrovic, 2010, 382). The model implementation does not end with the ending of a certain project or solving a certain problem, but can be applied for solving some other, similar problems (Sterman, 2000, 81).

ILLUSTRATION OF THE SYSTEM DYNAMICS MODEL APPLICATION

Let the object of the observation be a company that has introduced a new product to the market, with an to research the process and predict the dynamics of the adoption of the new product in the market. In that sense, an appropriate SD model providing the prediction of the dynamics of the adoption of a new product on the market can be developed. F. Bass (1969) gives preliminary assumptions of the models developed further within the SD conceptual framework (Morecroft, 2007; Sterman, 2000).

Figure 2 shows the model of a new product adoption and the identified key stocks, flows and feedback loops. This is the model inclusive of potential adopters, considering the word-of-mouth for the product only. The model, in which the adoption rate represents the result of the word-of-mouth, implies the two following assumptions (Bass, 1969): Above all, it is necessary that there be initial adopters, i.e. the value of this variable in the model must not be zero, which means that there must be one or more people who have already been using the product. Also, it is assumed that the product is bought only due to the information and recommendations of the current adopters. These kinds of assumptions limit the model generality, which can be prevented by advertising, an important determinant of a new product adoption on the market.

There are two key stocks (Sternan, 2000, 324-325): adopters and potential adopters, and the adoption rate is equal to adoption from the word-of-mouth. Also, there are two feedback loops – one, positive or reinforcing, represented by the word-of-mouth, and the other, negative or balancing, represented by market

saturation. The positive loop shows that, if there are more adopters, there will be more people who can orally propagate the product. First, this loop dominates the system and generates growth. Contrary to that, the negative loop slows the system down, since the number of potential adopters decreases due to market saturation (because each new adopter originates from potential adopters). The aim is to eliminate potential adopters, i.e. make all potential adopters be transformed into product adopters.

It is assumed that the total population (a potential product market) is made up of a million people occasionally talking about their shopping. This tendency is marked by the contact rate and is assumed to be 100. The number of adopter contacts with the rest of the population per year represents the multiplication of the contacts rate and adopters. Some of these contacts lead to product adoption (while the contact of two adopters cannot generate a product adoption). A probability that any randomly selected contact, i.e. the one between an adopter and a potential adopter, is equal to the proportion of potential adopters in

Figure 2 Key stocks, flows and feedback loops in the process of a new product adoption

the total population. This relation decreases if the process of adoption continues, and reaches zero, when the market is completely saturated. However, not all adopter contacts will result in product adoption. The fraction of successful contacts is called the adoption fraction, its assumed value is 0.02, which means that 2% of all contacts lead to product adoption. The contact rate and the adoption fraction determine the word-of-mouth.

Time is marked in years in the model, and dt represents a moment small enough to provide numeric accuracy. The number of adopters at a specific time equals the sum of the previous number of adopters and time ($t-1$) and the adoption rate over the interval dt . Contrary to that, the number of potential adopters at time t equals the subtraction of the previous number of adopters (i.e. the number of adopters for time $t-dt$) and the adoption rate over the interval. It is considered that, initially, there are 10 adopters among the total population of one million, so the rest are potential adopters. The adoption rate is equal to adoption from the word-of-mouth.

If the stated variables are marked like this:

A - adopters

AR - adoption rate

PA - potential adopters

IPA - initial potential adopters

AWM – adoption from word-of-mouth

CR - contact rate

AF - adoption fraction

TP - total population

then the following equations can be determined (Morecroft, 2007, 168- 169):

$$A = A(t - dt) + (AR) * dt \quad (3)$$

$$PA(t) = PA(t - dt) - (AR) * dt \quad (4)$$

$$IPA = TP - A \quad (5)$$

$$AR = AWM \quad (6)$$

$$AWM = CR * A * (PA/TP) * AF \quad (7)$$

The dynamics of product adoption by the word-of-mouth is shown in Figure 3, where initially there are only ten adopters who start transferring their own experiences, i.e. propagate a product. During the first five years, adopters and their followers very slightly influence the rest of potential adopters who have not heard of the product yet. According to that, in a certain period of time, the adoption rate is close to zero; however there is a relatively small growth compared to the total population of million people. During the fourth year, adopters begin to grow in number. Therefore, the largest number of the total population become product adopters in the time interval between the fifth and the eighth year from the product introduction to the market. After that, the adoption rate begins to fall, since market saturation grows.

If there were zero initial adopters, even with a million potential adopters, there would be no growth, since the product is not known. All the above stated demonstrates a need for the existence of initial adopters in order to start with the the word-of-mouth, which represents the key model assumption. It is necessary that more elements, such as product advertising, included in order to create a base of initial adopters. In that sense, this model can be expanded by introducing advertising and following their effects on product adoption (Morecroft, 2007, 171).

Since SD models can be applied to any dynamic system, there are a great number of case studies and examples of their successful use (Forrester, 1972; Sterman, 2000; Morecroft, 2007).

QUALITATIVE AND GROUP-MODEL BUILDING IN SYSTEM DYNAMICS

There are certain advantages in management problems solving in SD: SD's strength lies in an assumption that the structure is the key determinant of a system behavior and the structure can be represented by appropriate positive and negative feedback loops. The understanding of feedback structures can help managers to manage complexity better and provide

more efficient decisions for achieving their goals. Since SD models pointing out the key decision points and actions of the ones who make those decisions are included in the models, the consequences of the current policies can be determined and alternative strategies can be researched (Jackson, 2003, 78).

However, critics consider SD models as imprecise, and not strict enough, i.e. those models are usually built on ignoring certain theories in the researched field or without a sufficient amount of collected data. If SD models are imprecise, then a precise prediction of the future system states can all but be provided, at the same time it will be just partially useful to decision-makers (Jackson, 2003, 79 – 80).

Richardson (1996), too, states the following problems as the key ones in a further SD development: understanding models behavior, model validity, the improvement of practical models application, models accessibility and availability, qualitative versus quantitative modeling, i. e. identifying conditions in which it is better to use qualitative tools, as well as conditions that demand formal quantitative modeling, etc.

SD was based strictly on building quantitative models to last for a long period of time. Although SD models are a mathematical representation of problems and policy alternative, for the most part, the available information is not numerical by nature, it is rather

Figure 3 Dynamics of product adoption by the word-of-mouth

Source: Morecroft, 2007, 170

qualitative. In spite of a general agreement on the importance of qualitative data and tools during the SD models development, there are no clear descriptions of the purpose and time of their using.

The lack of an integrated set of procedures for acquiring and analyzing qualitative information makes a gap between the modeled problem and the problem model. The gap is even more visible when a model considers the use of the soft variables, such as consumers' satisfactions or products quality. Problems connected with the quantification and formulation of qualitative variables has led to the development of the qualitative SD (Coyle, 2000; Homer & Oliva, 2001; Luna Reys & Anderson 2003; Dhawan et al, 2011). In that sense, certain diagrams, such as causal loop diagrams, can be used as qualitative tools for policy conclusions without quantification and simulation (Coyle, 2000, 233).

However, there is a question if certain qualitative tools should be used with or without additional quantification and simulation. Although there are situations where qualitative instruments are used without additional quantification and simulation, simulation is almost always considered to be wanted in a policy analysis, even when there are some uncertainties and soft variables. In fact, it is necessary that a danger of conclusions made only according to qualitative tools as well as the limitations of the simulation models be recognized and understood. (Homer & Oliva, 2001). Some researches on the effects of the quantitative and qualitative modeling in SD demonstrate the fact that, for relatively simple problems, represented by simple diagrams, it is enough to use qualitative modeling tools in SD. On the other hand, for complex assignments, it is necessary that quantitative models and simulation be included (Dhawan et al., 2011, 321). In spite of the fact that quantification is useful, one should carefully try to quantify soft variables. This is about a research field extremely important for a further development of SD (Coyle 2001, 362).

It could also be concluded that the question of using qualitative data and tools in SD is not an adequate one. The adequate ones would be where and how. Although certain authors think that the significance of qualitative data mostly stands out in the conceptualization phase, and less in the model formulating phase, qualitative

data are present in all phases of the modeling process (Luna-Reyes & Andersen, 2003, 275). According to that, some of the key techniques for collecting qualitative data can be identified in each modeling phase – such as interview, Delphi technique, the nominal group technique, etc. (Luna Reyes & Andersen 2003, 287 – 292).

Another type of critiques in SD is connected with the unitary nature of management problem situations, i.e. the functionalist systems paradigm which is the base for SD. Problem situations in organizations represent certain subjective constructions and participant interpretations, because the identifying of certain structures considers a continual process of negotiating with participants i.e. clients in the modeling process. In the given context, a tendency to research an SD system objectively, from outside the system, with a help of models built on the feedback process, represents a very complex task to do. Also, in SD, we start with the fact that there is accordance upon the model purpose, which neglects the purpose and aim variety that different participants have in management problems solving (Jackson, 2003, 81).

Group model-building arises as a response to these critiques (Vennix, 1995; Vennix 1999; Rouwette, 2001) or participative modeling (Lane, 2010), which is trying to include different participants, i.e. clients perceptions and opinions, in the model-building process. This is, in fact, an attempt to apply SD to some insufficiently defined, i.e. unstructured problems, and in that way to approach an interpretative paradigm. The research of certain cognitive limitations, i.e. ways for increasing capacity of group data processing, on the one hand, and the way participants see and interpret different problem situations, on the other, are important in researching the group model-building effectiveness in unstructured problem situations (Vennix, 1999, 381).

In order to effectively face the unstructured problems the system dynamicists should, above all, accept the fact that in many situations it is not useful, or that all the phases of the modeling process are even impossible to use. As previously stated, in some situations, it is better to apply only certain qualitative tools without quantification and simulation (Coyle, 2000, Dhawan et al, 2011). The fact is that it is necessary to precisely

estimate the conditions and effects of the qualitative and quantitative modeling.

Beside the stated, it is necessary that different ways of inducing the team learning and effective communication within the groups be exposed to improve the modeling process. To ensure learning, participants have to become modelers. It is necessary that the participants take an active part in a model development to enable effective model learning. Generally, in estimating the group model-building effectiveness, it can be concluded that participating in the modeling process increases clients' commitment and makes the implementation easier (Rouwette, 2001, 32, Vennix, 1995, 55).

However, tending to approach the interpretive paradigm, SD risks losing its key functionalist feature to identify laws that govern the behavior of systems. It means that, above all, SD should keep its functionalist characteristics (Jackson, 2003, 81). In fact, certain knowledge and skills necessary for model building in SD should be combined with the appropriate skills and knowledge necessary for facilitating participation and negotiation within groups (Vennix, 1999, 392).

Certain SD deficiencies can be overcome by a combined use of SD and some other interpretive systems approaches, such as Soft System Methodology (Coyle & Alexander, 1996; Lane & Oliva, 1998; Rodriguez Ulloa & Paucar – Caceras, 2005). Besides, SD can be combined with other functionalist approaches such as Organizational Cybernetics (Schwaninger, 2004; Schwaninger & Perez Rios, 2008).

CONCLUSION

SD, as a relevant structuralist-functionalist systems methodology, is based on the theory of information feedback and control. It is adequate for solving complex – unitary management problems, i.e. problem situations. Management problem situations in SD are expressed by the feedback structure and the process within, represented by appropriate diagrams and mathematical system models.

SD models represent an extremely powerful tool for management problems solving within organizations.

Developed through an appropriate modeling process, the SD model can be used in redesigning adequate organization policies and/or structures. The modeling process itself is an extremely complex iterative process of the modeler's moving through certain phases. Although there are different classifications of the modeling process phases, the following phases can be identified: the conceptualization phase, i.e. identifying a problem and presenting it by feedback loops; the formulating phase, i.e. the phase of building a mathematical model represented by appropriate level and rate equations; the testing phase or model validation by comparing it to the realistic world; and the implementation phase, i.e. model application in designing policies for improving the results for an organization's functioning.

Based on the assumption that the structure generates a certain behavior, SD models enable the prediction of a future system behavior through computer simulations, which is shown on the example of a new product adoption on the market. The key hypothesis in the paper can be confirmed by researching the theoretical-methodological and applicative aspects of management problems modeling within the conceptual framework of SD.

In spite of a great number of successful SD model applications in management problems solving, the SD models have certain limitations. This is about different problems connected with the quantification of certain soft variables and possible imprecisions and mistakes to follow. Qualitative SD or qualitative modeling in SD accentuating the significance of a single or combined use of certain qualitative and quantitative tools in SD come to surface as a response to these deficiencies. The limitations connected with the functionalist paradigm which SD is based on, should also be mentioned. It is related to the fact that SD assumes the existence of accordance on the model purpose, by which different perceptions and clients i.e. participants in the modeling process are neglected. In that sense, there are tendencies that SD approaches to the interpretive paradigm through group model-building. Despite the fact that soft variables and participants' perceptions should be included in research, SD should not lose its key structuralist-functionalist features in tending to approach the interpretive paradigm.

Bearing in mind the identified deficiencies of SD and its models, it is necessary that different assumptions, conditions, and ways of a combined use of SD and other systems approaches to management be researched. SD can be used in combination with appropriate interpretive systems methodologies such as Soft System Methodology (SSM), where SD models represent an adequate support to SSM tools in research of organizations' structures and their functioning. Besides, SD could be combined with systems approaches that also belong to the functionalist systems paradigm, such as Organizational Cybernetics. A combined SD use, i.e. the SD model use with other methodologies, methods and techniques, represents a special field relevant for future researches.

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