Performance effects of information systems integration:
A system dynamics study in a media firm

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Abstract

Purpose – The purpose of this paper is to understand the relationship between information systems (IS) integration and business performance in the context of the ad traffic system of a media company.

Design/methodology/approach – A system dynamics (SD) model that shows ad traffic system structure was developed and simulation scenarios were examined.

Findings – Simulation scenarios identify the dysfunctional effects of the lack of IS integration. The model shows how IS integration problems increase the dynamic complexity of business processes, resulting in poor business performance. It also shows how and why IS integration improvements can lead to superior performance.

Research limitations/implications – Researchers of business process management will benefit from a wider adoption of simulation and SD modeling approaches. The modeling process and model validation are discussed.

Practical implications – SD modeling can help organizations analyze and streamline their business processes through IT, significantly and sustainably improving their business performance.

Originality/value – Modeling the relationship between IS integration and business performance through time.

Keywords Information systems, Integration, Business performance, Modelling, Information media

Paper type Research paper

1. Introduction

The 2008 Beijing Olympics presented a unique profit opportunity from advertising for entertainment and media firms worldwide. The Beijing Olympics coverage by European Union's Television Network (EUTV Net), a pseudonym to protect the company in this study, represented a most significant coverage of the Olympics by a major European TV network. It marked a new phase in sports-content treatment from the Far East on a live basis. New regulations from the International Olympic Committee reduced restrictions on advertising and its content. Coupled with the ten channels EUTV Net devoted to the Olympic Games, it planned to turn the 2008 Olympics into a highly profitable enterprise for this media giant, with monetary gains expected to exceed €2.5 billion. More than half a year prior to the start of the Olympics, an impressive group of top-tier companies committed to funding its advertising. To meet the needs of advertisers and to capitalize on its ability to generate sales in a strong advertising environment, EUTV Net had pledged more than 3,600 h of commercial coverage throughout the two-week event.

Poised to benefit from this prospect, EUTV Net's objective was to maximize monetary gains by making its ads play on time, error free, and with minimal duplication. EUTV Net formed a system dynamics (SD) modeling team to analyze its advertisement

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(ad) traffic system during and around the Beijing 2008 Olympics. Extracted from that project is a purely deterministic SD model that simulates the flow of ad content or ad traffic through the EUTV Net around and during the Beijing 2008 Olympic Games. It highlights areas in need of particular attention in terms of either redesign or intensive monitoring to ensure the successful and seamless operation of ad traffic at EUTV Net during the two-week Olympic Games period. Most importantly, it identifies the dysfunctional effects of lack of IS integration, and it examines the performance implications of improved IS integration in the ad traffic processes.

The SD model of EUTV Net's ad traffic system offers a rigorous approach to seeing the benefits of enterprise IS integration. One important insight of this study is that lack of IS integration increases dynamic complexity[1] of business processes. That increases both operational failure cost and management or coordination cost through a feedback-loop structure of multiple interdependencies among cause-and-effect variables. Thus, the benefit from improving IS integration is that dynamic complexity is being reduced, which decreases operational and management costs, leading to superior business performance.

The paper makes multiple contributions. One is the culmination of the ad traffic situation at EUTV Net into a SD model that allows addressing specific performance concerns at EUTV Net. Articulating exactly how distinct elements of ad traffic IS structures interact through time, the SD model enables the examination of simulation scenarios, gaining insight into how and why the model produces the results it does. The SD modeling process aims at helping managers of both manufacturing and service firms articulate exactly how the structure of circular feedback relations among variables in the system they manage determines its performance through time (Sterman, 2000, 2001).

Two, the paper fills a gap in the information systems (IS) literature by modeling the adverse effects of the lack of IS integration. Driven by internal growth, mergers and acquisitions (M&As), and technological change, firms are plagued with IS integration challenges (Davenport, 1998). But the literature has not yet shown exactly how IS integration or the lack of it impacts performance (Barki and Pinsonneault, 2005). It also shows that simulation modeling is useful in evaluating the performance improvement from increasing IS integration.

Three, by describing SD modeling and showing its value, the paper encourages a wider adoption of the SD method in enterprise and business process modeling and analysis in order to improve business performance.

2. Ad-traffic systems flowchart and integration

EUTV Net's Beijing Olympics proposition hold the potential for large-scale revenue. Thus, Olympics-related advertising was a high priority for the firm's ad media center (MC) and spec center (SC), charged with the successful queuing and broadcasting of all ad content. The flowchart in Figure 1 shows a highly simplified depiction of ad traffic processes and system components at EUTV Net during and around the Beijing 2008 Olympic Games.

On the top left of Figure 1, ad sales contracts, sports-related ad traffic, and reconciliation (recon) reports, after ads play, feed the spec database 1, within EUTV Net's SC. The database also incorporates non-sports promotional (promo) elements. The SC spec database or log guides ad media at MC, formatted for standard television (SDTV: media system 1) and high-definition TV (HDTV: media system 2). On the lower half of Figure 1, spec databases 2 and 3 handle both specs and play schedules for

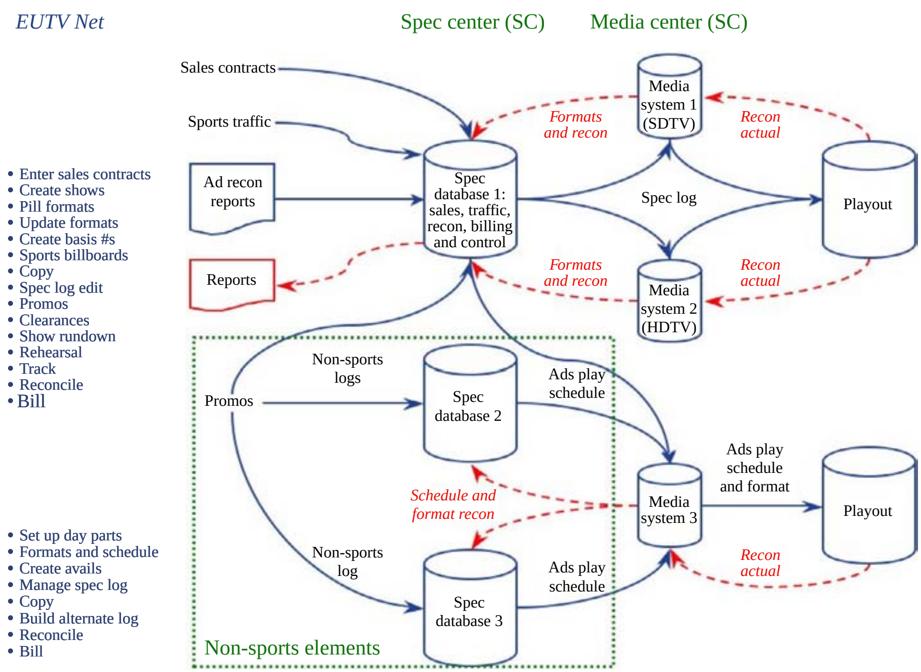


Figure 1.
Flowchart of Beijing 2008 Olympics ad traffic at EUTV Net

promos not directly linked to Olympics sports content. They guide ad content of the media mounted on media system 3.

Signed ad sales contracts signal ad agents to fax ad instructions or specs to SC and to send media to MC (Figure 1). The lack of IS integration between MC and SC requires EUTV Net workers to manually log and re-log data from MC computers to SC computers, and vice versa. When SC changes its spec log, then MC workers must manually update the appropriate media system. If MC alters media, either because of format errors or because of recon actual reports after playout, now SC workers must manually update the pertinent spec database. Imagine how time consuming and costly these rework feedback loops get, given that EUTV Net does not operate just one, but ten affiliated TV network channels or stations.

To put the flowchart in Figure 1 into perspective, EUTV Net suffers from lack of data integration, because multiple databases hold duplicate and non-standardized data that are entered manually (Goodhue *et al.*, 1992). It also suffers from lack of process integration, because subsystems do not share data, ad traffic processes are not streamlined, and several process steps are paper-based requiring manual data entry from one subsystem to another. For many organizations, integration is supported through enterprise IS (Davenport, 1998; Markus, 2001). These systems are capable of sharing information across the extended enterprise from suppliers to customers, promising reduced costs and increased service quality and customer satisfaction (Shore, 2006). Integration can also be supported by enterprise application integration (EAI) technologies that offer interconnection, while preserving existing and legacy systems (Hasselbring, 2000; Themistocleous *et al.*, 2001). In addition, today's firms need mature enterprise information technology (IT) architectures (Ross, 2003).

Enterprise IT architecture maturity is achieved in four stages of increasing maturity: "business silos", "standardized technology", "rationalized processes" and "business modularity". In the first stage of enterprise IS architecture maturity, disparate IT applications that address local needs characterize business silos, not integrated to share enterprise-wide data. Given the lack of IS integration between its SC and MC, respectively, EUTV Net fits squarely in the business silos stage of IT architecture maturity, with low performance implications for the company as a whole.

In the context of enterprise systems (ES) integration, Gattiker and Goodhue (2004) suggest that high interdependence among organizational sub-units (e.g. SC and MC) contributes to positive ES effects, because ES facilitate information flows and coordination. In their framework, interdependence is a construct drawn from the organizational information processing theory and it means "the degree to which sub-units must exchange information or material in order to complete their tasks" (p. 433). Volkoff *et al.* (2005) argue that ES-enabled integration varies depending on the relationship between the integrated business units (e.g. similar plants or stages in a business process) and that the variation can be understood based on Thompson's (1967) three types of interdependence (pooled, sequential, and reciprocal). However, the "exact nature of the relationships among integration, organizational performance, and implementation effort is currently poorly understood and moderating and mediating factors remain largely unexplored" (Barki and Pinsonneault, 2005, p. 165).

The flowchart in Figure 1 serves well as a rough-cut map. Like this flowchart, however, most process and all standard operating procedure (SOP) models are merely textual and diagrammatic in nature. But relying on diagrammatic intuition for testing logical consistency in dynamic business processes might contrast sharply with human cognitive limits (Morecroft, 1985; Paich and Sterman, 1993; Sastry, 1997; Sterman, 1989). Simulation modeling is needed to gain deep insight into process performance (Georgantzas and Ritchie-Dunham, 2003) and to analyze the relationship between IS integration and performance.

3. Model description

This section presents a seven-sector SD model of the ad traffic model at EUTV Net, which entails dynamically complex processes. The model's time horizon is 28 days (672 h). Week one represents preparation time, including receipt of advertising content and its entry into multiple IS that slate it into appropriate spots. Weeks two and three represent ad playout during the Beijing 2008 Olympics, with eight-hour coverage per day across EUTV Net's ten affiliated TV channels or stations. Week four entails auditing and reconciliation needed to determine whether all ad content airs at appropriate spots, including calculations related to agreed upon ratings and number of duplicate ads.

The subsystem diagram of Figure 2 shows the model's seven sectors, dynamically interconnected through bundled connectors and flows. The subsystem diagram also shows an IS integration on-off switch, which can drastically affect system structure. It instigates IS integration as a zero-one dummy variable: 0 = "IS integration" and 1 = "no IS integration".

Ad sales model sector

SD uses stock and flow diagrams to depict relations among variables in a system (Sterman, 2000). The structure of relations among variables in a system gives rise to its

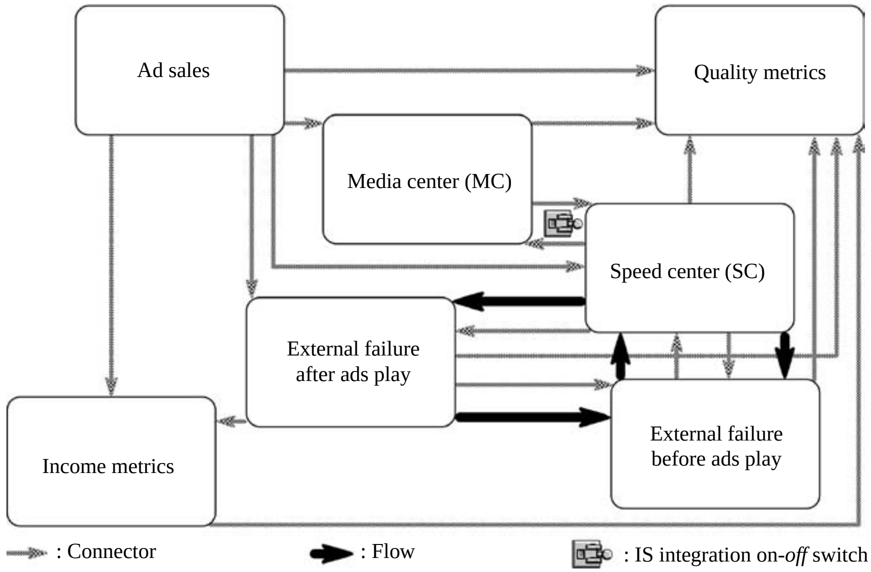


Figure 2.
Subsystem diagram of ad traffic at EUTV Net

behavior (Sterman, 2001, p. 16). Figure 3 shows the stock and flow diagram of EUTV Net's ad sales model sector, reproduced from the simulation model built with the iThink® (Richmond, 2007) SD software.

There is a one-to-one correspondence between the model diagram in Figure 3 and its Equations (Appendix Table AI). Building the model entailed first drawing the model structure and then specifying equations and parameter values.

In SD, rectangles represent stocks or level variables that can accumulate, such as the Ads Sold stock in Figure 3. Emanating from cloud-like sources and ebbing into

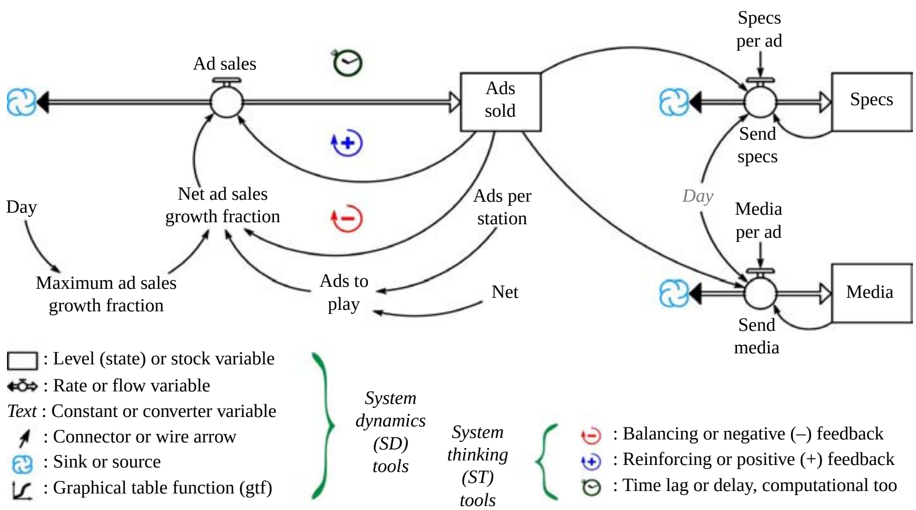


Figure 3.
Ad sales model sector

cloud-like sinks, the double line, pipe-and-valve-like icons that fill and drain the stocks represent flows or rate variables that cause the stocks to change. The send media flow (lower right, Figure 3) feeds the media stock, for example, driven by the Ads Sold level. Single-line arrows represent information connectors, while circular or plain text icons depict auxiliary converters where behavioral relations, constants, or decision points convert information into decisions. EUTV Net's ads to play capacity, for example, depends on both its ads per station capacity and the firm's ten TV network or net stations.

In Figure 3, the net ad sales growth fraction, which determines ad sales, is a downward sloping or linearly declining function of the Ads Sold stock, relative to its ads to play capacity at EUTV Net's ten station network or net. Initialized at a small, unitless fraction of EUTV Net' ads to play capacity, Ads Sold follows a logistic growth pattern (Richardson, 1991). The S-shaped logistic model helps explain and predict EUTV Net's Ads Sold, a real quantity that cannot grow forever.

The ad sales it models typically grow in a fixed ads scheduling environment: given EUTV Net's ads to play capacity, as more ads sell, ad sales eventually decline. Once signed, sales contracts signal ad agents to send their media and pertinent ad instructions or specs to EUTV Net's MC and SC, respectively. Depending on the Ads Sold level, the media per ad, and specs per ad constant parameters determine what ad agents send to EUTV Net's MC and SC.

Media center

As ad media reaches EUTV Net's MC (Figure 4 and Appendix Table AII), they create a backlog of media at MC. MC workers must prep and mount media in this backlog to make Media Ready. The prep media rate can be time consuming, depending on the media format (analog or digital). MC workers always check media for errors as they prep them to feed the Media Ready stock, but media error can strike any time without warning, causing media to err.

Reducing the media errors backlog might entail error discovery and recovery, and even involve external agents messing up, for example, a courier damaging media, but

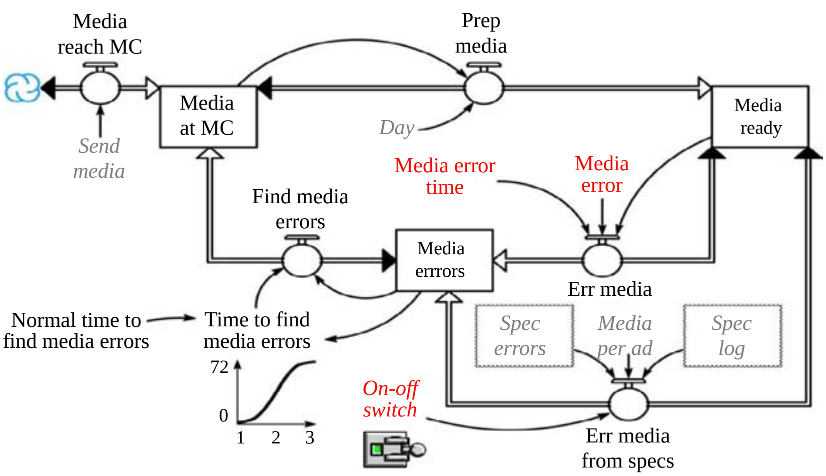


Figure 4.
MC model sector

EUTV Net's MC always takes responsibility to find media errors. The time to find media errors is an increasing function of media errors (Garcia, 2006, p. 145), abiding to the cumulative normal curve requirements (Franco, 2007). Moreover, even if faultless and ready to air, media can also err from specs, because of the lack of IS integration between EUTV Net's MC and SC (on-off switch = 1).

Spec center, and external failure before and after ads play

Ads Sold generate ad specs, which reach EUTV Net's SC via facsimile (Figure 5 and Appendix Table AIII). Faxed specs that contain ad instructions build the Specs at SC backlog, which SC workers deplete via the log specs rate. This is a tedious, time-consuming job, redolent with complicated details, as opposed to dynamic complexity. Much like their MC counterparts, SC workers always check specs for errors as they log them to feed the Spec Log stock, but spec error can also strike any time, again without warning.

EUTV Net deems critical to make its Spec Log as error free as possible. So, its SC log editors check and re-check ad specs to determine whether they are ready for play or not. Reducing the Spec Errors backlog entails spec error discovery and recovery, but it takes both time and lots of human interaction to find spec errors. In addition to the SC-specific errors, ad specs can also err from media, because of the lack of IS integration between EUTV Net's MC and SC.

External failure BEFORE ads play

External failure before ads play is possible when an event is rescheduled. To give but one example, this might entail the Olympics swimming events pushed back a few days because of technical problems with some underwater photo finish equipment. The swimming-related ads will either lose their spot or be reshuffled by SC log editors until satisfactory. But scrambling to find free spots also takes time. In the model, the External Errors backlog (lower left, Figure 5) also adds to Spec Errors. It does so while EUTV Net's SC log editors scramble to find free ad spots, which they lose, because of external failure before ads play.

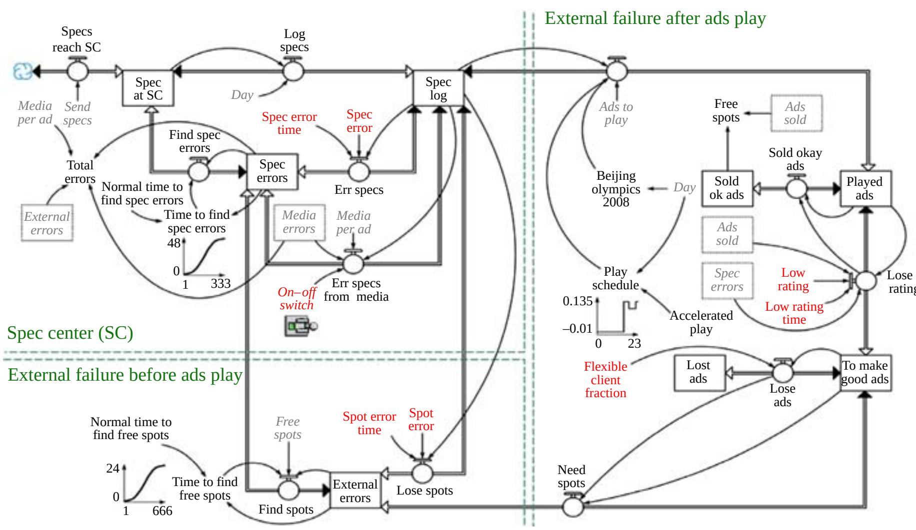


Figure 5.
SC and external failure before and after ads play model sectors

External failure AFTER ads play

In addition to losing ad spots before ads play, External Errors can also occur after ads play, attributed to low program ratings (middle right, Figure 5). If failures occur after ads play, per its extant contractual obligations and depending on how flexible its clients are, EUTV Net must handle ads that receive low ratings after playout to make good on them.

On the top right of Figure 5, the play ads rate concurrently depletes the Spec Log backlog and feeds the Played Ads stock, according to EUTV Net's play schedule. Depending on EUTV Net's ad accelerated play per hour, the play schedule function is discontinuous mode to emulate the discontinuous playout of advertising content during the Beijing 2008 Olympics, with eight hours of daily coverage, including prime time (6-10 pm), across EUTV Net's ten TV net stations.

Most ads play fine and receive the high ratings that EUTV Net anticipates, so they feed the Sold OK Ads stock, at the sold okay ads rate. Among Played Ads, those that receive a low rating because, for example, viewers switch channels to watch the news of the day, fill the To Make Good Ads stock, at the lose a rating rate. Depending on ad contracts and how flexible or inflexible its clients are, EUTV Net can either lose ads to feed its Lost Ads stock or need spots to make good on ads that played smoothly but received low ratings. The available free spots that EUTV Net can use to make good on ads that received low ratings after playout is the algebraic difference between the Ads Sold stock minus the Sold OK Ads stock.

Income metrics

Ads Sold and the average price per ad co-determine EUTV Net's potential revenue. The product of the average seconds per ad times the average price per second parameters determines the average price per ad. Similarly, average price per ad and sold okay ads co-determine EUTV Net's sales revenue rate, which feeds the total revenue stock. The potential revenue minus total revenue difference produces EUTV Net's revenue gap and total revenue minus lost revenue gives its total net revenue. Again, all this entails strictly operational cost terms, excluding fixed overhead coordination and management costs.

Quality metrics

Little's (1961) law helps compute the average residence time of specs and faulty specs (errors) in their respective backlogs through the ratio of the pertinent stock in transit to its outflow rate (Appendix Table AVII). Three of these ratio metrics contribute to the internal failure cost rate. There, a fourth ratio metric, average time to log errorless specs, deflates the internal failure cost rate from EUTV Net's ideal, i.e. errorless, operating cost, so that the internal failure cost rate does not in turn inflate the internal failure cost stock it feeds. The average time to find spots contributes to EUTV Net's external failure cost rate, together with the average price per ad, average wage, program coverage, and net parameters. The external failure cost rate feeds the external failure cost stock which, together with the internal failure cost stock co-determine EUTV Net's total failure cost. Last but not least, the total revenue stock minus EUTV Net's total failure cost converter difference produces the firm's total net gain, strictly in operational cost terms once more.

4. Simulation scenarios

The simulation results show five scenarios of what might happen to EUTV Net's ad traffic during and around the Beijing 2008 Olympics. Table I shows the first four of these scenarios that the purely deterministic SD model computes. They assess potential implications for EUTV Net's performance, in terms of income and quality metrics, as error severity and frequency increase incrementally. The first or ideal scenario assumes that all ad traffic runs smoothly at EUTV Net, with zero errors in ad media and specs, and without any external errors causing lost ad spots and low ad ratings. Moreover, all clients are flexible with ad spots. Thus, scenario is useful to let EUTV Net know what its performance metrics might potentially look like, if 0 (zero) errors were humanly feasible.

Then, the base-, worse- and worst-case scenarios in Table I explore how EUTV Net's income and quality metrics might respond to the incrementally increasing error severity and frequency. To give but one example of what the terms "error severity and frequency" and their respective scenarios mean, let us follow the incremental changes in the low rating and low rating time parameters given in Table I. Incrementally increasing error severity means that unanticipated world events might make TV viewers switch channels, their moving away from the Beijing Olympics sports events, potentially causing 2,222, 4,444, and 6,666 low ad ratings at a time, respectively, under the base-, worse- and worst-case scenarios in Table I, respectively. Incrementally increasing error frequency means that these low ad ratings occur every three, two and one days, respectively, under the base-, worse- and worst-case scenarios in Table I, respectively.

The four computed scenarios in Table I emulate ad traffic at EUTV Net as is: with its ad MC and SC functioning as business silos, without IS integration, i.e. on-off switch = 1 (one). A fifth scenario that the SD model computes, not shown in Table I, entails the same error severity and frequency as the #4: Worst-case scenario in Table I does, but with IS integration, i.e. on-off switch = 0 (zero). This scenario offers a unique opportunity for EUTV Net to rigorously assess the potential benefits of enterprise IS integration.

Figure 6 shows results for the ad sales, MC, and SC sector metrics at EUTV Net, under the computed scenarios in Table I. Through time, ad sales feeds Ads Sold, which in turn cues ad agents to send their ad media to EUTV Net's MC. The media stock lags

Run	Media error (media)	Media error time (h)	Spec error (spec)	Spec error time (h)	Spot error (spec)	Spot error time (h)	Low rating (spec)	Low rating time (h)	Flexible client fraction
No. 1: Ideal	0	168 (7 d)	0	144 (6 d)	0	120 (5 d)	0	96 (4 d)	1.00
No. 2: Base	3	144 (6 d)	222	120 (5 d)	2,222	96 (4 d)	2,222	72 (3 d)	0.95
No. 3: Worse	6	120 (5 d)	444	96 (4 d)	4,444	72 (3 d)	4,444	48 (2 d)	0.90
No. 4: Worst	9	96 (4 d)	666	72 (3 d)	6,666	48 (2 d)	6,666	24 (1 d)	0.85

Notes: d, day; h, hour

Table I.
Computed scenarios of increasing error severity and frequency

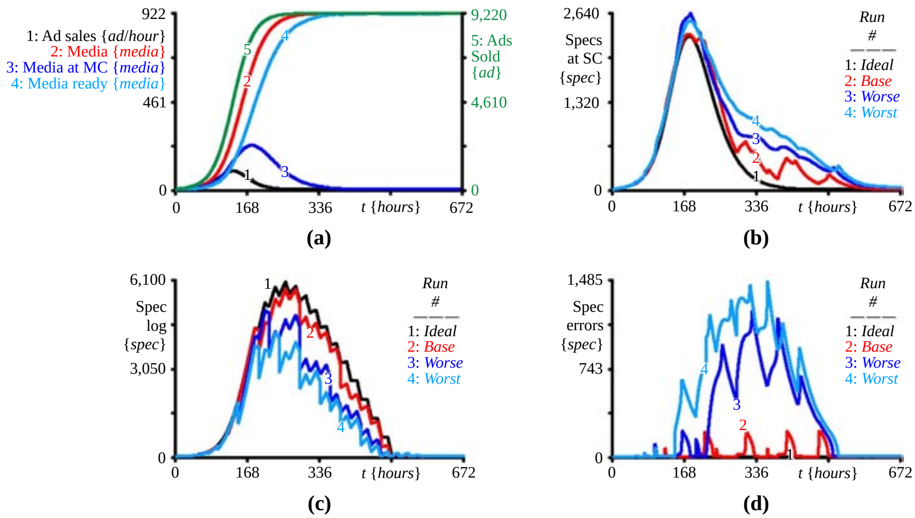


Figure 6. Computed scenarios for ad sales, MC and SC metrics at EUTV Net

behind Ads Sold because it takes time for ad agents to prepare and send their ad media to MC. Similarly, the Media Ready stock lags behind media because of the time it takes EUTV Net's MC workers to receive, mount, and inspect ad media before they render Media Ready for playout.

The difference in amplitude between ad Media at SC and ad Media Ready represents the extra number of ads that go into the MC and SC computer systems to ensure continuous operation in the event of errors. Similar to the logistic growth of Ads Sold in Figure 6(a), media and Media Ready increase at an increasing rate until they reach their respective inflection points. Thereafter, like Ads Sold, they increase concurrently at a declining rate and then plateau as the Olympics commence and ad operations begin to slow down in terms of preparation. Past the 504-h mark, EUTV Net will only focus on reconciliation and will not be entering any new data other than to correct internal and external failures. In addition, the smooth behavior of the five metrics in Figure 6(a) persists undisturbed under all four scenarios in Table I.

That is not, however, the case for the Specs at SC stock. Here, (Figure 6(b)), the Specs at SC backlog responds differentially under the base-, worse- and worst-case scenarios of Table I. Once these three scenarios of incrementally increasing error severity and frequency play, Specs at SC overshoots EUTV Net's ideal or errorless Specs at SC and remains high thereafter, contributing to EUTV Net's internal failure cost.

Likewise, the Spec Log backlog (Figure 6(c)) responds differentially under the base-, worse- and worst-case scenarios. But unlike Specs at SC, Spec Log remains proportionally lower than under the #1: Ideal-case scenario of Table I. What causes the anomalous dynamics of Specs at SC and Spec Log is the fire-like Spec Errors accumulation (Figure 6(d)). Without IS integration at EUTV Net, Spec Errors is caught inside a malicious web of 52 interdependent feedback loops, causing both Specs at SC to inflate inside its own web of 25 feedback loops, and Spec Log to deflate, the latter backlog also caught inside 48 loops.

The time-series graph in Figure 7(a) shows the relations through time among Spec Log, Played Ads, and Sold OK Ads, under the No. 1: Ideal-case or errorless scenario in Table I. Focusing first on the Spec Log backlog, its curve increases in a step pattern. During the week prior to the Olympics the ads to play increase. As ads play out in the second week, the first week of the Olympics, Spec Log peaks on the fourth day of the Olympics and then gradually drops as each day passes and the amount of Ads Sold is reaching its saturation point of 9,220 ads (Figure 6(a)).

Ads Played varies wildly because the Olympics-related ads play for eight hours a day, 1/3 of a day's programming per channel. EUTV Net fills the remaining 16 h with regular network programming and regular ads. Ads Played during the Olympics programming are in fact the peaks of the Ads Played curve, which flat lines a day after the Olympics because there are no Olympics Ads Sold left to show.

Sold OK Ads are the ads played fine, i.e. without errors, during the Olympics (Figure 7(a)). ETVU Net sells ad time prior to the games, but collects its revenue after sold ads actually show on its airwaves. This explains why Sold OK Ads (Figure 7(a)), total revenue (Figure 7(b) and 7(d)), and total net revenue (Figure 7(c)) all increase in a step pattern. EUTV Net collects no revenue until after the first day of the Olympics. Its revenue curves increase when it collects revenue for the prior day's ads shown and then slightly plateau while next day's programming plays. EUTV Net then collects next day's revenue. This pattern continues until the day after the Olympics and then plateaus, as EUTV Net has no revenue pending to collect from Olympics ads.

Under the ideal or errorless playout scenario in Figure 7(b), through time, EUTV Net's potential revenue increases, total revenue comes closer and closer to its potential revenue, and its revenue gap reacts inversely. Potential revenue is the perceived monetary € stream of what the network might receive at the end of the run in ads. The day after the Olympics begin, EUTV Net's total revenue starts to move up to match its potential revenue from Olympics-related ads and so does its total net revenue (Figure 7(c)). Its revenue gap begins to decrease the day after the start of the Olympics because of realized total revenue (Figure 7(b)).

But the effects of incrementally increasing error severity and frequency can easily diminish EUTV Net's income metrics. If the base-, worse- and worst-case scenarios of Table I materializes, then the network might anticipate less total net revenue (Figure 7(c)). As its total revenue falls short of matching its potential revenue in

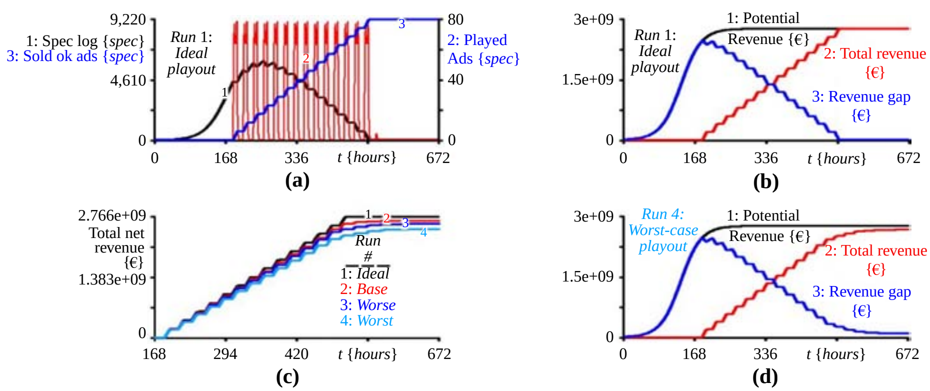


Figure 7.
Computed scenarios for SC and income metrics at EUTV Net

Figure 7(d), its revenue gap, the difference between total revenue and lost revenue (Appendix Table AVI), remains positive, well above zero at the end of the SD model's time horizon of 672 h or 28 days (four weeks).

Looking more closely at what causes the step-pattern dynamics of variables in Figure 7, Played Ads behaves quite differently under the computed ideal- and worst-case ad playout scenarios at EUTV Net (Figure 8). Under the worst-case playout scenario, the fire-like Spec Errors accumulation (Figure 6(d)) depletes the Spec Log backlog (Figure 6(c)), thereby causing EUTV Net to run short of ads to play on days 13 and 14 of the Olympics (Figure 8). The reduced Spec Log reduces Played Ads, which get further reduced as low ratings increase To Make Good Ads (right, Figure 5). To Make Good Ads in turn feeds External Errors, thereby driving Spec Errors even higher, which in turn depletes Media Ready via media errors (Figure 4). Closing the loop, because of EUTV Net's lack of IS integration, media errors further depletes the Spec Log backlog (Figure 5). This makes EUTV Net's ten stations play and re-play ads during the ad reconciliation week, still showing Olympics ads 21 days after the 14-day long Olympics start and end.

The phase plot in Figure 9(a) shows that, under the ideal playout scenario, there is no correlation between ETVU Net's Sold OK Ads and Lost Ads. But under the incrementally increasing error severity and frequency scenarios of Table I, the higher Sold OK Ads are, the higher Lost Ads get, also because of inflexible clients. Also, as errors and inflexible clients increase, so does the correlation between these two variables.

Conversely, as error severity and frequency increase, the correlation between EUTV Net's internal failure cost and total net gain gets smaller (Figure 9(b)). But, as the phase plot in Figure 9(b) shows, if EUTV Net integrates its MC and SC computer systems, i.e. on-off switch = 0, then, under the No. 5: Worst-case playout scenario (Figure 9(b)), it might see more than a 37 percent reduction in its internal failure cost, coupled with a slight increase in its total net gain, during the 28-day horizon around the Olympics.

The IS integration scenario sequesters EUTV Net's internal failure cost not only below the results of the No. 4: Worst-, but also below the No. 3: Worse-case, without

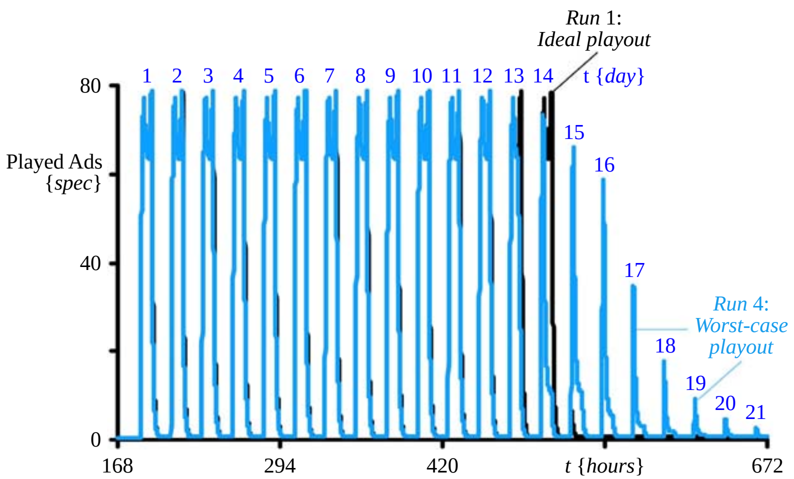


Figure 8.
Computed ideal- and worst-case ad playout scenarios at EUTV Net

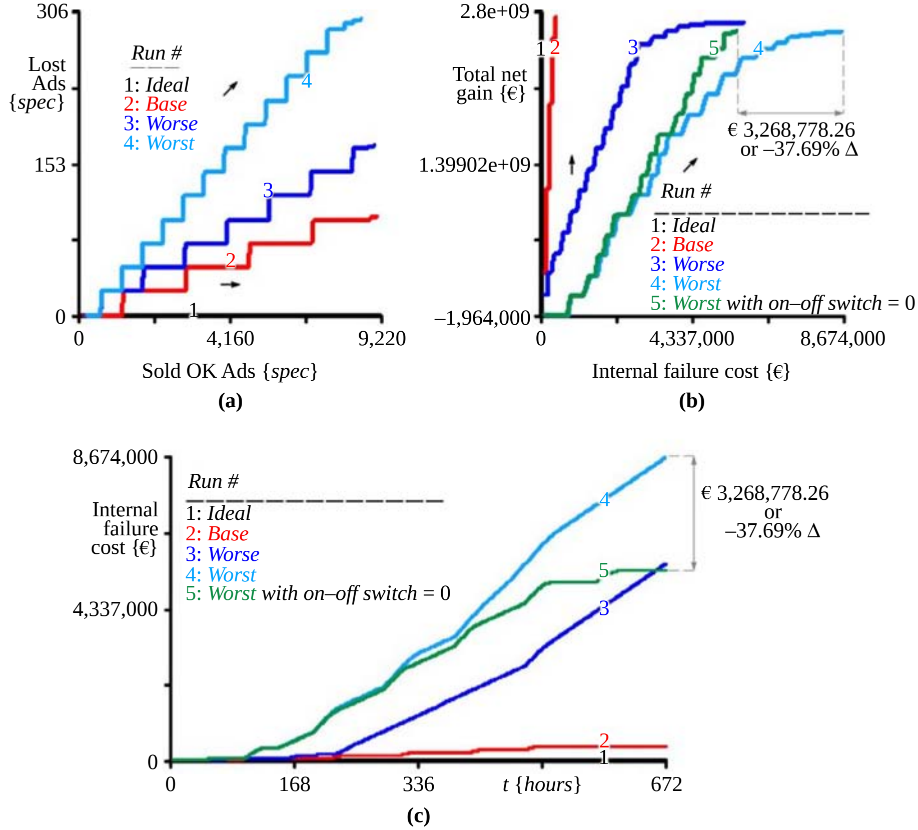


Figure 9.
Computed scenarios for SC and quality metrics at EUTV Net

IS integration playout scenario (Figure 9(c)). Given that through its 4-week time horizon the model computes EUTV Net's potential internal failure cost savings at €32,68,778, over a 52-week horizon, IS integration might benefit EUTV Net by more than €42 million in annual internal failure cost savings.

5. IS integration and business performance

The lack of integration in companies can be painful. It stops firms from developing effective end-to-end business processes. Instead of sharing data seamlessly across IT systems, multiple sources of unstandardized data and transferring data manually from one system or database to another become prevalent. Processes are neither fully automated nor optimized. Symptoms of organizations lacking IS integration include high IT costs, poor data for decisions, slow, ineffective decision making (Goodhue *et al.*, 1992), poor coordination and low transparency, lack of flexibility, lack of shared understanding, and other strategic and intangible effects that change through time (Stefanou, 2001). The result is dysfunctional performance with intricate cost or error dynamics. But what is the exact mechanism that connects IS integration and business performance?

Our model offers a novel answer: IS integration affects dynamic complexity which affects performance. The model instigated IS integration with its on-off switch

(Figures 2-5), which drastically affects system structure and, thereby, system behavior and business performance (Figure 9). Flipping the switch from one to zero reduces EUTV Net's ad traffic dynamic complexity, i.e. interdependencies among variables connected through multiple feedback loops. Dynamic complexity can be measured by the number of feedback loops that affect the behavior of important system variables.

Consider Figure 4, Because of lack of IS integration between EUTV Net's MC and SC, media can err from specs. With the on-off switch = 1, the Media Ready stock is caught inside 16 feedback loops and the media errors backlog inside 30 loops. With IS integration, i.e. on-off switch = 0, the Media Ready loops drop down to three and the media errors loops down to four, respectively. Thus, lack of IS integration causes the firm's ad traffic system to attain a high level of dynamic complexity, which increases errors and degrades operational performance.

In addition, the lack of IS integration feeds the SC's Spec Errors backlog (Figure 5), while making EUTV Net's ad traffic system attain increased dynamic complexity. With the on-off switch = 1, the Specs at SC backlog is caught inside 25 feedback loops, the Spec Log stock entails 48 loops and the Spec Errors backlog 52. With IS integration, i.e. on-off switch = 0, the Specs at SC backlog loops drop from 25 to 19, the Spec Log stock loops drop from 48 to 21, and the Spec Errors from 52 to 26 loops, respectively.

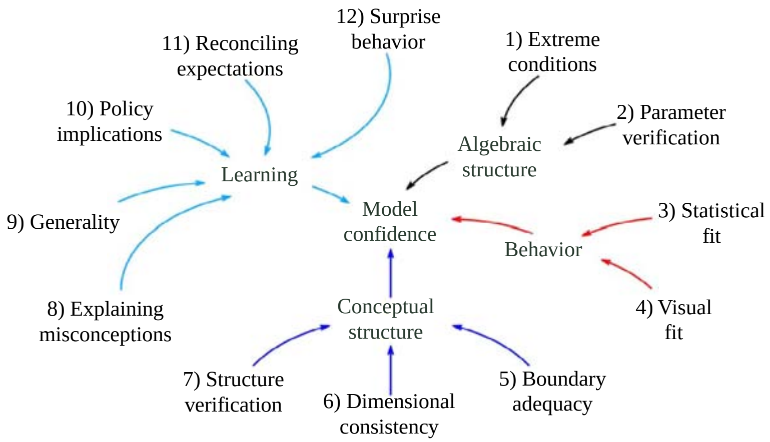
The model that this paper shows excludes all fixed overhead and coordination (Malone and Crowston, 1994), i.e. management, cost considerations at EUTV Net. In reality, however, these costs are substantial. During and around the Olympic Games, EUTV Net anticipates its coordination cost to skyrocket as its managers scramble, day and night, to find ways to make ad content at EUTV Net on time, error free, and carried out with a minimal duplication of effort. Thus, our simulation results probably underestimate the performance improvement when IS integration problems are alleviated.

Management costs are also a direct result of high dynamic complexity due to lack of integration. Intuitively, the cost of understanding and managing or controlling a system increases when the system's dynamic complexity is high. Conversely, reducing the dynamic complexity of a system lowers its management cost.

6. Model validity

Model validation is an important aspect of a successful SD project (Bell and Senge, 1980; Forrester and Senge, 1980; Morecroft, 2007, Sterman, 2000). Any model that purports to explain the evolution of a dynamic process also defines a dynamic system either explicitly or implicitly (Repenning, 2002). A crucial aspect of model building in any domain is that any claim a model makes about the nature and structure of relations among variables in a system must follow as a logical consequence of its assumptions about the system. Also, attaining logical consistency requires checking if the dynamic system the model defines can generate the expected performance of the dynamic process the model tries to explain (Morecroft, 2007).

The influence diagram (ID) in Figure 10 shows four test groups that can help build confidence in SD models. The diagram shows algebraic and conceptual structure tests, as well as behavior and learning tests. Any one of them alone cannot prove model validity. But combined, they might help modelers see a model's quality and usefulness (Morecroft, 2007, p. 410).



Source: Adapted from Morecroft (2007, p. 411)

Figure 10.
Tests that build confidence in SD models

Does the SD model of EUTV Net's ad traffic around the Beijing 2008 Olympics pass the test gauntlet in Figure 10? To build confidence in the model, what follows draws heavily on Morecroft's (2007, Ch. 10).

Algebraic structure tests

The model responds quite robustly to the extreme range of increasing error severity and frequency. Under the No. 4: Worst-case scenario in Table I, almost one-third of the ads that EUTV Net anticipates to sell fail either internally or externally, both before and after ads play. Moreover, EUTV Net data helped verify all model parameters.

Behavior tests

As the model was developed before the Olympics, EUTV Net did not have any actual data from the games. However, the Ads played dynamics (Figures 7 and 8) provides a perfect visual fit with EUTV Net's regular playout and Olympics rehearsals. Given the lack of actual data from the future, our SD modeling team did not formally test for magnitude, shape, periodicity, and phasing of trajectories. The visual fit is, however, "a common and effective way to build confidence in a model because it is a criterion people readily understand, even if they are not modelers" (Morecroft, 2007, p. 410).

Conceptual structure tests

Boundary adequacy refers to the endogeneity of closed-loop feedback structures that cause dynamics (Meadows, 1980). Assuredly the model passes this test with flying colors. Its subsystem diagram (Figure 2) shows seven sectors dynamically interconnected through bundled connectors and flows, which reveal the multiple closed feedback loop structures that generate EUTV Net's ad traffic SD. Moreover, the model is not only dimensionally correct, but also verifiably consistent with descriptive knowledge about EUTV Net's ad traffic system during and around the Beijing 2008 Olympics (Figure 1).

Learning tests

The use of model sectors (Figure 2) enables partial model tests to avoid misconceptions. Custom-built, the SD model shows the peculiarities of EUTV Net's ad traffic system.

Parts of it are generic, however, it incorporates common assumptions behind seemingly diverse processes in economics, epidemiology, marketing, and sociology, such as, for example, the S-shaped logistic or growth model (Figure 3). Widely used for modeling population growth, innovation diffusion, sales, and other social phenomena, EUTV Net's ad sales model sector also conforms to the ecological concept of carrying capacity.

In addition to providing a perfect visual fit with EUTV Net's regular playout and Olympics rehearsals, the Ads Played dynamics (Figures 7 and 8) allowed comparing computed scenarios with expectations and reconciling opinions about anticipated ad traffic behaviors at EUTV Net. Last but not least, it is indeed daunting to see how one commercial spot and its playout involve so many interacting parts to properly show the ad and to collect revenue. Even the mental models of our modeling team's members have been surprised by how many interdependent feedback loops our formal SD model helped unearth.

7. Discussion

The Beijing 2008 Olympics was a unique profit opportunity for EUTV Net, with clients flocking for advertising time during this international event and fewer restrictions on ads during coverage, as compared to all previous Olympics. That gave EUTV Net incredible hours of coverage with volumes of ads. The great capacity for ad spots and volume per day required a system that is dynamic in reaction to live sporting events with big revenue stakes. EUTV Net formed a SD modeling team to analyze its ad traffic system during and around the Beijing 2008 Olympics.

EUTV Net's ad traffic system is both combinatorially complicated and dynamically complex. It is daunting just to see how one commercial spot and its playout involve so many interacting parts to properly show the ad and to collect revenue. The SD modeling process helped our modeling team at EUTV Net accomplish the task of capturing the processes required to complete the cycle of services purchased, services rendered, and revenue received by EUTV Net.

We found that the lack of IS integration has deleterious effects on business performance, along both income and quality metrics, because it increases the dynamic complexity of the system under management. SD modeling can help companies assess the dynamic complexity of their processes and systems, and evaluate simulation scenarios that may lead to improved business performance.

Simulation scenarios suggest that the pathway of opportunity for EUTV Net is to ascend to a more mature enterprise IT architecture stage than its current business silos one (Ross, 2003; Venkatesh *et al.*, 2007). The next stage, standardized technology, involves the implementation of a set of IT standards shared by all IT applications. This stage is followed by the next stage, rationalized processes, whereby enterprise-wide IS integration supports optimized business processes. EUTV Net cannot skip a stage in improving its IT architecture maturity because important lessons learnt at each stage enable firms to move on to the next one. Ascending to a more mature IT architecture stage through IS integration might yield significant performance improvements as our findings show.

As IS integration problems challenge numerous companies, SD modeling can provide a tool for understanding these problems, optimizing business processes, and achieving stronger, sustainable performance via more mature enterprise IT architectures or related interventions (Georgantzas and Katsamakas, 2008). More generally, the paper calls for a wider adoption of SD simulation modeling in business process analysis and management (Sharif, 2005). SD modeling offers a rigorous methodology to model "as-is" and "to-be" systems within the same model (e.g. the on-off switch in the current model), to evaluate system performance through time, to unearth relevant managerial mental models, and to explain performance of interest through the feedback-loop structure that determines this performance. Integrating SD process modeling with business process management tools and frameworks, for example Malone *et al.* (1999), is another promising direction for research and business performance improvement.

Complexity theory and the exponential increase in computational power make simulation a critical fifth tool in addition to the four tools used in science for theory building: observation, logical/mathematical analysis, hypothesis testing, and experiment (Davis *et al.*, 2007; Turner, 1997). Simulation modeling with SD permits business researchers and practitioners to examine the aggregate, dynamic, and emergent implications of the multiple, nonlinear, generative mechanisms embedded in the processes capabilities and resources of every modern organization (Oliva and Sterman, 2001; Repenning and Sterman, 2002).

Note

1. Complexity must not be confused with the simple-complicated dimension (Georgantzas and Katsamakas, 2008). Complicated uses the Latin ending -plic: to fold, but complex contains the Greek root *πλέξ-* "*plēx-*": to weave. A complicated structure is thereby folded, with hidden facets. A complex structure has interwoven parts with interdependencies that cause dynamic complexity. Thus, complex is the opposite of independent or untwined.

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Appendix

Table AI.
Ad sales model sector equations

	Equation no.
Level (state) or stock variables {unit}	
Ads Sold(t) = Ads Sold(t − dt) + (ad sales) * dt	1
INIT Ads Sold = 0.004 * ads to play {*ad*}	1.1
Media(t) = Media(t − dt) + (send media) * dt {*Note*: an ad consists of two parts: media and specs}	2
INIT Media = 0 {*media*}	2.1
Specs(t) = Specs(t − dt) + (send specs) * dt {Again, each ad consists of two parts: media and specs}	3
INIT Specs = 0 {*spec*}	3.1
Flow or rate variables {unit}	
ad sales = MAX (0, net ad sales growth fraction * Ads Sold) {*ad/hour*}	4
Send media = MAX (0, (Ads Sold * media per ad - Media)/day) {*media/hour*}	5
Send specs = MAX (0, (Ads Sold * specs per ad - Specs)/day) {*spec/hour*}	6
Auxiliary or converter variables and constants {unit}	
ads per station = 922 {*ad/station*}	7
ads to play = ads per station * net {*ad*}	8
day = 24 {*hour*}	9
Maximum ad sales growth fraction = 1/day {1/*hour*}	10
media per ad = 0.1 {*media/ad*}	11
net = 10 {*station*}	12
net ad sales growth fraction = maximum ad sales growth fraction * (1 − Ads Sold/ads to play) {1/*hour*}	13
specs per ad = 1 {*spec/ad*}	14

Table AII. MC model sector equations

	Equation no.
Level (state) or stock variables {unit}	
Media at MC(t) = Media at MC(t − dt) + (media reach MC + find media errors − prep media) * dt	15
INIT Media at MC = 0 {*media*}	15.1
Media Errors(t) = Media Errors(t − dt) + (err media + err media from specs − find media errors) * dt	16
INIT Media Errors = 0 {*media*}	16.1
Media Ready(t) = Media Ready(t − dt) + (prep media − err media − err media from specs) * dt	17
INIT Media Ready = 0 {*media*}	17.1
Flow or rate variables {unit}	
err media = IF (Media Ready >0) AND (INT (TIME/media error time) = TIME/media error time) THEN (MIN (media error/DT, Media Ready/DT)) ELSE (0) {*media/hour*}	18
err media from specs = MAX (0, REWORK (on-off switch * Spec Errors/(1e − 9 + Spec Log) * media per ad/DT)) {*media/hour*}	19
find media errors = MAX (0, Media Errors/time to find media errors) {*media/hour*}	20
media reach MC = MAX (0, send media) {*media/hour*}	21
prep media = MAX (0, 0.5 * Media at MC/day +0.3 * Media at MC/(2 * day) +0.2 * Media at MC/(3 * day)) {*media/hour*}	22
Auxiliary or converter variables and constants {unit}	
media error = 9 {*media*}	23
media error time = 96 {*hour*}	24
normal time to find media errors = 1 {*hour/media*}	25
time to find media errors = GRAPH (Media Errors * normal time to find media errors) {*hour*}	26
(1.00, 0.447), (1.20, 1.64), (1.40, 4.81), (1.60, 11.4), (1.80, 22.2), (2.00, 36.0), (2.20, 49.8), (2.40, 60.6), (2.60, 67.2), (2.80, 70.4), (3.00, 71.6)	

Table AIII.
SC model sector equations

	Equation no.
Level (state) or stock variables {unit}	
Specs at SC(t) = Specs at SC(t - dt) + (specs reach SC + find spec errors − log specs) * dt	27
INIT Specs at SC = 0 {*spec*}	27.1
Spec Errors(t) = Spec Errors(t − dt) + (err specs + find spots + err specs from media − find spec errors) * dt	28
INIT Spec Errors = 0 {*spec*}	28.1
Spec Log(t) = Spec Log(t − dt) + (log specs − err specs − lose spots − play ads − err specs from media) * dt	29
INIT Spec Log = 0 {*spec*}	29.1
Flow or rate variables {unit}	
err specs = IF (Spec Log >0) AND (INT (TIME/spec error time) = TIME/spec error time) THEN (MIN (spec error/DT, Spec Log/DT)) ELSE (0) {*spec/hour*}	30
err specs from media = MAX (0, REWORK (on-off switch * (Media Errors/media per ad)/(1e − 9 + Spec Log)/DT)) {*spec/hour*}	31
find spec errors = IF (Spec Errors >0) THEN (Spec Errors/time to find spec errors) ELSE (0) {*spec/hour*}	32
log specs = MAX (0, 0.5 * Specs at SC/day +0.3 * Specs at SC/(2 * day) +0.2 * Specs at SC/(3 * day)) {*spec/hour*}	33
specs reach SC = MAX (0, send specs) {*spec/hour*}	34
Auxiliary or converter variables and constants {unit}	
normal time to find spec errors = 1 {*hour/spec*}	35
on-off switch = 1 {*unitless*}	36
spec error = 666 {*spec*}	37
spec error time = 72 {*hour*}	38
total errors = External Errors + (Media Errors/media per ad) + Spec Errors {*spec*}	39
time to find spec errors = GRAPH (Spec Errors * normal time to find spec errors) {*hour*}	40
(1.00, 0.298), (34.2, 1.09), (67.4, 3.21), (101, 7.62), (134, 14.8), (167, 24.0), (200, 33.2), (233, 40.4), (267, 44.8), (300, 46.9), (333, 47.7)	

Table AIV. External failure before ads play model sector equations

	Equation no.
Level (state) or stock variable {unit}	
External Errors(t) = External Errors(t − dt) + (lose spots + need spots − find spots) * dt	41
INIT External Errors = 0 {*spec*}	41.1
Flow or rate variables {unit}	
find spots = IF (External Errors > 0) THEN (MIN (External Errors/time to find free spots, free spots/time to find free spots)) ELSE (0) {*spec/hour*}	42
lose spots = IF (Spec Log > 0) AND (INT (Time/spot error time) = Time/spot error time) THEN (MIN (spot error/DT, Spec Log/DT)) ELSE (0) {*spec/hour*}	43
Auxiliary or converter variables and constants {unit}	
normal time to find free spots = 1 {*hour/spec*}	44
Spot error = 6666 {*spec*}	45
Spot error time = 48 {*hour*}	46
Time to find free spots = GRAPH (External Errors * normal time to find free spots) {*hour*} (1.00, 0.149), (67.5, 0.546), (134, 1.60), (200, 3.81), (267, 7.40), (334, 12.0), (400, 16.6), (466, 20.2), (533, 22.4), (600, 23.5), (666, 23.9)	47

Table AV. External failure after ads play model sector equations

	Equation no.
Level (state) or stock variables {unit}	
Lost Ads(t) = Lost Ads(t − dt) + (lose ads) * dt	48
INIT Lost Ads = 0 {*spec*}	48.1
Played Ads(t) = Played Ads(t − dt) + (play ads − lose a rating − sold okay ads) * dt	49
INIT Played Ads = 0 {*spec*}	49.1
Sold OK Ads(t) = Sold OK Ads(t − dt) + (sold okay ads) * dt	50
INIT Sold OK Ads = 0 {*spec*}	50.1
To Make Good Ads(t) = To Make Good Ads(t − dt) + (lose a rating − need spots − lose ads) * dt	51
INIT To Make Good Ads = 0 {*spec*}	51.1
Flow or rate variables {unit}	
lose a rating = IF (Played Ads > 0) AND (INT (Time/low rating time) = Time/low rating time) THEN (MIN (low rating/DT, Played Ads/DT) + REWORK (Spec Errors/Ads Sold/DT)) ELSE (0) {*spec/hour*}	52
lose ads = IF ((1 − flexible client fraction) * To Make Good Ads/DT > 0) THEN ((1 − flexible client fraction) * To Make Good Ads/DT) ELSE (0) {*spec/hour*}	53
need spots = IF ((To Make Good Ads − lose ads)/DT > 0) THEN ((To Make Good Ads − lose ads)/DT) ELSE (0) {*spec/hour*}	54
play ads = IF (TIME > 168) AND (Spec Log > 0) THEN (MIN (PULSE (Spec Log * play schedule), ads to play/Beijing Olympics 2008 * play schedule)) ELSE (0) {*spec/hour*}	55
Sold okay ads = MAX (0, Played Ads − lose a rating) {*spec/hour*}	56
Auxiliary or converter variables and constants {unit}	
accelerated play = 1 {1/*hour* ^ 2}	57
Beijing Olympics 2008 = 336/day {*unitless*}	58
flexible client fraction = 0.85 {*unitless*}	59
free spots = MAX (0, Ads Sold − Sold OK Ads) {*spec*}	60
low rating = 6666 {*spec*}	61
low rating time = 24 {*hour*}	62
Play schedule = GRAPH (MOD (accelerated play * TIME, day)) {1/*hour*} (0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.124), (16.0, 0.124), (17.0, 0.124), (18.0, 0.0954), (19.0, 0.0954), (20.0, 0.0954), (21.0, 0.0954), (22.0, 0.124), (23.0, 0.124)	63

	Equation no.
Level (state) or stock variables {unit}	
Lost Revenue(t) = Lost Revenue(t − dt) + (lost sales revenue) * dt	64
INIT Lost Revenue = 0 {€}	64.1
Total Revenue(t) = Total Revenue(t − dt) + (sales revenue) * dt	65
INIT Total Revenue = 0 {€}	65.1
Flow or rate variables {unit}	
lost sales revenue = average price per ad * (lose a rating + lose ads) {€/hour}	66
sales revenue = average price per ad * sold okay ads {€/hour}	67
Auxiliary or converter variables and constants {unit}	
Average price per ad = average price per second * average seconds per ad {€/ad}	68
Average price per second = 750,000/30 {€/second}	69
Average seconds per ad = 12 {second/ad}	70
Potential revenue = average price per ad * Ads Sold {€}	71
Revenue gap = potential revenue − Total Revenue {€}	72
Total net revenue = Total Revenue − Lost Revenue {€}	73

Table AVI.
Income metrics model sector equations

	Equation no.
Level (state) or stock variables {unit}	
Errorless SC Specs(t) = Errorless SC Specs(t − dt) + (errorless specs reach SC − log errorless specs) * dt	74
INIT Errorless SC Specs = 0 {*spec*}	74.1
External Failure Cost(t) = External Failure Cost(t − dt) + (external failure cost rate) * dt	75
INIT External Failure Cost = 0 {€}	75.1
Internal Failure Cost(t) = Internal Failure Cost(t − dt) + (internal failure cost rate) * dt	76
INIT Internal Failure Cost = 0 {€}	76.1
Flow or rate variables {unit}	
Errorless specs reach SC = MAX (0, send specs) {*spec/hour*}	77
external failure cost rate = MAX (0, average time to find spots * average wage * net * program coverage + average price per ad * lose ads) {€/*hour*}	78
Internal failure cost rate = MAX (0, (average time to fix media errors + average time to fix spec errors + average time to log specs − average time to log errorless specs) * average wage * net * program coverage) {€/*hour*}	79
log errorless specs = MAX (0, 0.5 * Errorless SC Specs/day +0.3 * Errorless SC Specs/(2 * day) +0.2 * Errorless SC Specs/(3 * day)) {*spec/hour*}	80
Auxiliary or converter variables and constants {unit}	
Average time to find spots = External Errors/(1e − 9 + find spots) {*hour*}	81
Average time to fix media errors = Media Errors/(1e − 9 + find media errors) {*hour*}	82
Average time to fix spec errors = Spec Errors/(1e − 9 + find spec errors) {*hour*}	83
Average time to log errorless specs = Errorless SC Specs/(1e − 9 + log errorless specs) {*hour*}	84
Average time to log specs = Specs at SC/(1e − 9 + log specs) {*hour*}	85
Average wage = 20 {€/*hour/station*}	86
Program coverage = 1 {1/*hour*}	87
Total failure cost = External Failure Cost + Internal Failure Cost {€}	88
Total net gain = Total Revenue − total failure cost {€}	89

Table AVII.
Quality metrics model sector equations

About the authors

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