European Journal of Operational Research 199 (2009) 793–800

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Integration of business function models into an aggregate enterprise systems model

Cecilia Temponi [a,*], Michael D. Bryant [b], Benito Fernandez [b]

[a] Texas State University, McCoy College of Business, San Marcos, TX 78666, United States
[b] The University of Texas, Mechanical Engineering, Austin, TX 78712, United States

ARTICLE INFO

Article history:
Available online 12 August 2008

Keywords:
System integration
Model development
Supply chain strategy
Operations management
Complexity

ABSTRACT

Introduced are methods that combine models of distinct business functions into an aggregate model of an enterprise system to assist management's strategic decision making. Models of individual business functions are reviewed, and equations quantifying relationships presented. Using methods of system theory, including block diagrams, non-dimensionalization, and state equation methods, these business function sub-models were assembled into a composite enterprise systems model. The formulated aggregate model is illustrated with industry examples for tire companies; nonetheless the aggregate model can be used to assess other industries. Values of parameters for the system model were determined from data obtained from annual reports of publicly owned companies. Simulations closely matched the companies' published performance over ensuing years. The developed aggregate enterprise model has significant predictive capabilities for modern corporations.

1. Introduction

Enterprises experienced significant technological and managerial changes over the last decades. Changes have been forced by various events: global competition, workforce changes, new technology, and continuously changing customers' preferences. Enterprises must harmonize structure and deal with competition in an increasingly complex and vaguely understood business environment (Temponi et al., 1999; The Economist, 1999). A business organization is considered a society with growth, differentiation, hierarchical order, controls, competition, communications, relationships, etc. The business organization or enterprise is viewed as a socio-cultural system (Von Bertalanty, 1968). Managers and leaders should view organizations as flexible work groups with information flow across the business functions, instead of vertically arranged discrete functions with well-defined boundaries. Von Bertalanty (1968), Temponi (1992) and Kosanke et al. (1999) indicated that modeling of organizations in the context of a system involves many difficulties:

- Enterprise structures have complex dynamics. Companies organize by products, processes, hierarchical structures, matrix structures, or hybrids.
- Variables to assess performance in organizations are difficult to identify and measure, and often clouded by employee and management emotions.
- Relations between enterprise components are difficult to identify and quantify. Descriptions are usually qualitative and subjective.
- Multiple time scales associated with enterprise functions affect grouping of functions, and how feedback can update decisions.

An enterprise must quickly accommodate change, maintain profits, address internal issues, continuously improve, quickly deliver products and services, serve internal and external customers, satisfy customers' expectations, develop human resources, and cope with regulations. Today's enterprises have adopted process driven structures and constant innovation (Kim and Jang, 2002; Olhager et al., 2002; Ding and Eliashberg, 2002; Champy, 1995).

Managers often structure or restructure organizations based on hunch or feel. To remain competitive, enterprises must sometimes adopt untested practices. Needed are modeling methods to assess the effectiveness of decisions, before implementation. This has been hindered by difficulties in enterprise modeling (Von Bertalanty, 1968; Temponi, 1992; Kosanke et al., 1999; Jorysz and Vernadat, 1990).

This paper integrates several existing models of business functions (Feichtinger et al., 1994; Vidale and Wolfe, 1953; Nervalone and Arrow, 1962; Bass, 1969; Porter and Taylor, 1972; Mak et al., 1976; Sethi, 1977; Abad, 1982; Spremann, 1985; Srinivasan et al., 2000) into an aggregate enterprise systems model, using system dynamics methods. We develop an approach to efficiently combine functional models into an enterprise's aggregate model. The objective is to demonstrate how to combine sub-models into aggregate models that can track reality, and thus be useful to management's strategic decision making. These models are not

* Corresponding author.
E-mail addresses: c.temponi@txstate.edu (C. Temponi), mbryant@mail.utexas.edu (M.D. Bryant), benito@mail.utexas.edu (B. Fernandez).

0377-2217/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.ejor.2008.08.007

Nomenclature

$A(t)$	stock of advertising goodwill, $
$S(t)$	sales rate, $ per unit time
$\Lambda(t)$	instantaneous sales, $ per unit time
$u(t)$	current advertising rate, $ per unit time
$R(t)$	reputation, $ per unit time
$p(t)$	selling price, $ per unit sold
p^0	selling price, $ per unit sold
δ	goodwill depreciation constant, per unit time
η	elasticity of demand with respect to price, non-dimensional
ω	elasticity of demand with respect to advertising, non-dimensional
$\phi(R(t))$	function that converts reputation to sales, $ per unit time
$h(p^0/p)$	experience function, see Eq. (3), non-dimensional
γ	rate of depreciation of reputation, per unit time
c	unit production cost
r	discount rate
$I(t)$	level of inventory, number of units
$v(t)$	rate of production, units per time
C_v	unit cost of raw materials, labor and other production
ρ	sales response constant, per unit time
M	saturation level of sales rate, $ per unit time
NI	net income, $ per unit time
F	fixed costs, $ per unit time
$v^*(t)$	desired rate of production, units per time
$I^*(t)$	desired inventory, number of units
l	sales decay constant, per unit time
A_0, I_0, R_0, S_0	initial values of variables

intended for quantitative description of manufacturing processes. No judgments or assessments will be made in this article. A strategic model can be useful to any industry or environment. Section 2 reviews related literature on organizations and strategy. Section 3 examines pertinent functional enterprise models. Section 4 integrates these business models into an aggregate enterprise model. In Section 5, publicly available data is used to "tune" the aggregate strategic enterprise model to a specific company. We demonstrate this approach on tire companies; however, this approach can be extended to a variety of organizations. Interpretation of results and limitations of the approach are discussed in Section 6. Conclusions and future directions are presented in Section 7.

2. Theory development

Organization, corporation, and enterprise will be treated as equivalent terms. An enterprise has been defined as a dynamic set of interacting elements, including technical processes, organizational processes, technical functions, departments, business centers, and subsystems such as finance, production, marketing, and management (Temponi, 1992). An element of an enterprise serves multiple roles, and interacts with other elements and with the environment (Senge, 1990; Temponi et al., 1999). Elements of an enterprise include men, machines, buildings, inflow of materials and orders, outflow of goods and services, monetary values, human relations, and management (Temponi, 1992). Elements and interrelationships can be dynamic. The arrangement of elements and management of resources produces a complex and scalable system (Senge, 1990; Jorysz and Vernadat, 1990; Von Bertalanty, 1968). Complexity evolves because components interact in multiple ways (Temponi, 2006). Customers, internal or external, receive finished goods or services (Evans and Lindsay, 2005).

Speed and automation of internal processes benefit customers and suppliers. The ability to consider customers, suppliers, and distributors as collaborators introduces issues for competitive advantage of an organization (Malone et al., 1999). Metrics, strategy, and complexity in such integrated enterprise systems are challenging and studied by Taylor (1998), Goodstein and Butz (1998), Hope (1998), and Anderson et al. (1994).

3. Related work on enterprise models

Past enterprise models focused on specific functions of a company. In this section, we review existing models of business functions. Each of these models treats other business functions as constants or external inputs. Table 1 lists the models most relevant to this study. Some of these models describe business dynamics with difference equations, while others use differential equations. Each model defines its variables (such as sales or inventory); often definitions of the same variable differ between models. These issues were major challenges in the development of the approach for a strategic aggregate enterprise model.

3.1. Nervalone and Arrow model for advertising

Nervalone and Arrow's (1962) model equated rate of change $\dot{A} = \mathrm{d}A/\mathrm{d}t$ of advertising goodwill $A(t)$ to the difference between

Table 1
Summary of some enterprise models

Proposer	Model's emphasis/limitations
Vidale and Wolfe (1953)	Relates advertising and sales functions/applicability bounded by the two functions aimed at in the model
Nervalone and Arrow (1962)	Relates dynamics of current and past advertising expenditures incurred by a firm, to demand for its products/model is used as a base for other marketing models
Bass (1969) and Srinivasan et al. (2000)	Model for marketing (Established theory of adoption and diffusion of consumer durables. Developed many types of diffusion models to address various issues surrounding the sales growth of new durables and electronics.)/model well used in the marketing field
Porter and Taylor (1972)	Relates production and inventory functions/domain specific to the functions for which the model was developed
Mak et al. (1976)	Extended the work of Porter and Taylor/applicable to production and inventory functions
Sethi (1977)	Extended the Vidale and Wolf (1953) model and expanded on the rate of sales and the forgetting factors/pertinent to expansion of original model only
Abad (1982)	Proposed a model with interaction of production and marketing functions, based on the production model of Holt et al. (1960) and the advertising model of Vidale and Wolfe (1953)/operational applicability
Spremann (1985)	Relates customer's experience after consumption of a good or service with the reputation of the company and the price/operational applicability to variables incorporated in the model