Methodological analysis of supply chains management applications

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1. Introduction

Supply Chain Management (SCM) is concerned with material and information flows between facilities and the final consumers. The planning of all production and marketing facilities should be formulated and may be considered more comprehensive of management activities than the field of Operations Management [3]. In many organizations it is useful to develop plans over time and study the precision obtainable. On the other hand, strategic SCM is concerned with structural modifications to enhance productivity. However, the success or failure of the SCM policy will depend on how the plan is operationally implemented [51]. Within a given organizational structure, an operational SCM plan is formed by selecting a chain of activities in time to realize the firm’s objective or more generally a sequence of alternative activities are considered from which the actual path is selected step by step on the basis of suitable criteria. Plans may consist of a single activity or may be very complex structures, requiring involved selection processes to be implemented.

Approaches to formulate management plans may be based on expert knowledge and anecdotal considerations, so this includes the positivist methodology, examined in Section 2.1, or on an interpretative methodology to treat examples to integrate the accrued scientific experience, discussed in Section 2.2 or thirdly a formal nonlinear, dynamic and stochastic representation of particular plans to derive the set of activities to be pursued, considered as instruments to achieve the goals desired, see Section 2.3. Thus methodologies might provide different selections of activities with possibly different results and plans. The reasons to adopt a particular methodology to choose a set of activities and/or a particular implementation [5] may arise from different considerations: to accept a familiar approach implementable on experience [42,1], to apply a common sense, psychological or sociological interpretation of phenomena [36], or finally to formulate a formal detailed dynamic nonlinear stochastic estimation implementation [20]. How should the specific methodology be chosen with regard to the formulation of the plans, the results to be evaluated with regard their likelihood, their realizability and precision? These crucial questions should be determined before embarking on an operational plan.

The aim of this paper is consequently to examine different management methodologies to determine the accuracy achievable in operational SCM plans, a study which appears to be new in this context [20,19].

To formulate plans and to control their execution, it is necessary to observe (in a technical sense) and measure the inputs and outputs during their realization, or at least at the start and at the end of the plan [48,29]. The first two methodological approaches traditionally assume the flows or values of activities as observable, but if some are unobservable, as demand schedules, which cannot be verified directly, they must be surmised. In the instrumental methodology, dynamical system representation of the operational SCM allows to observe these variables through the representations,
within formal systems, by instrumental variables [35,48] and by the determination of the state-of-the-system [29,19].

Comparative evaluation and verification methods of experimental procedures require general statistical experimental designs [15] to avoid personal preferences subjective evaluations or a priori considerations. Common sense designs and experimental evaluations cannot be used in applied sciences, as irreversible and unpredictable changes generally occur, so experimentation cannot be carried out by intuitive or a priori approaches based on experience, but requires formal statistical methods [35]. In the positivist and in the interpretative approaches parameters and functional forms of a model are presumed known on the basis of experience, as in ‘soft O.R.’, which constitute accepted behavioural, psychological or sociological procedures [12], but must be regarded as subjective procedures. Thus there is a growing concern in the SCM field to determine effective comparisons and integrate results between differently implemented methods, such as case, survey-based and secondary data based approaches. Multiple methodological approaches, holistic, econometrics, path analysis, system modelling and mathematical applications must also be compared as indicated [4]. However, many SCM professionals feel that there may be a real danger of shifting from empirical data sources to formal modelling approaches to the detriment of the traditional disciplinary methodologies [9,47]. A similar concern arose in Chemistry in the Eighteenth Century to support and defend the ‘Pilogistion’ theory against Lavoisier’s view, which generated the theory and methods of modern Chemistry and showed the sterility of the defense of the earlier approach [28]. Similar concerns befall classical Physics, essentially a Neo–Kantian methodology [34] rather than the mathematical nonlinear approaches to Physics (general relativity approach), associated with Logical Positivism.

Formal approaches to SCM have been applied through general dynamic processes, by adaptive planning and by general supply chain dynamics. General variational models have been proposed, but the functional and parameter structure are assumed to be observable or perceivable [37], which can lead to contradictions, since a representation of a phenomenon may not yield a solution, while the phenomenon considered exhibits a stable precise solution. Uncertain dynamical systems are extensively studied under positivist or interpretative methodologies, albeit the presumption that the values of parameters be known, result in a conditioning by random effects and therefore ambiguous [21].

To be logically consistent, plans must be discriminatory, i.e. at every period conditions must be evaluated and specified accurately so that the activities indicated can be continued, modified, delayed or abandoned in the next period [6]. Essentially, this requires that the plan be verifiable at every stage over the horizon. If the plan cannot be periodically verified, as any chosen activity which should be coherent with the formal plan may turn out false, a logical contradiction may ensue: from a given premise a conclusion and its opposite could be reached [2].

The plan of the paper is the following. In Section 2 different management methodologies will be presented and the principal postulates or axioms that characterise each alternative will be given. As two of the three approaches have logical limitations, these need not be examined further, so in Section 3 the modelling of SCM with the instrumentalist management methodology is discussed and the way to formulate computational viable plans is indicated, while in Section 4 implementations of well known SCM management planning problems, such as bullwhip effect and collaborative planning problems will be examined from all three methodological viewpoints concluding that for the first two approaches the plans are subject to logical contradictions and of little use. Instead for the instrumental approach the problems can be solved correctly. Considerations will be examined as relevant conclusions in Section 5.

2. Management methodologies

An SCM plan is satisfactory if, sufficiently frequently, events predicted ex-ante are equivalent to those actually occurring ex-post. When the decision processes are formulated by optimal control algorithms and results are coherent in a high proportion of instances, then the plan satisfies the ‘Certainty Equivalence’ criterion [19]. Various other approaches could achieve similar results so it is important to examine if this is verifiable.

Models to formulate SCM plans should be analysed for their logical consistency, which is a prerequisite to the analysis of an implementation while their statistical correctness and the adequacy of the results is a requisite of a methodology so as to determine and verify the best formulable operational plan, according to the objectives, for a given precision. Thus the necessary experimental design should be enacted for comparison and evaluation and it must be shown that from acceptable premises or axioms, by suitable deductions, an operational plan can be specified which will constitute an implementation of the scientific method [53]. As the suggested plan is generally not replicable, it cannot be comparably tested by suitable experimental designs. However, formal methods may be used to ensure that the methodology applied is logically correct and implementable so the formulation of the plans in the ex-ante form should be analogous to the ex-post outcome.

A theory is a set of general related principles which are shown to be valid in a given contextual domain, while a methodology is a set of postulates or axioms from which the theory is derived. These postulates may be categorical, conditional or normative. Each principle derived in a theory is called a theorem, or a proposition and may be general, specific or hypothetical (logic of the conditional) [5]. Further a model is syntactically correct if it can be cast as a formal system, composed of formal definitions, axioms (or assumptions), derived theorems, incorporating, if need be, other required axiom systems (mathematics, statistics, numerical analysis etc.).

Axioms of the theory must be proved to be complete, independent and consistent [2]. All propositions derived in the system can be checked for logical consistency and correctness in their derivation. This assures that, if the derivations are also consistent, the application is syntactically correct and will not lead to contradictory results. In computer science this requirement is known as ‘Mathematical Verification’. However, this may not guarantee that the policy is useful or applicable, since excessive simplifications or unwarranted assumptions may have been introduced to ensure syntactical correctness. Thus the semantic adequacy of the syntactically correct model must be evaluated. A model is semantically adequate if the results of all known legitimate applications of the phenomenon can be reproduced by the model within a given level of accuracy, which is specified a priori according to the needs of the organization. In particular, if there is no set of input variables, which provide a determinate solution when applied to the phenomenon, assuming the control variables have been properly represented in the model, the results will form a nonsensical solution and the model will not be semantically adequate. Again in computer science this requirement is called debugging, which should always be pursued adamantly.

The predicted outcomes of syntactically correct and semantically adequate models, emerging from different approaches, can be compared by confronting the results predicted to outcomes which are syntactically correct and adequate semantically and form a correct standard. If one or more models do not fulfill these conditions, no confidence can be assigned to the potential outcome of these and the implementation may actually be contradictory and this will entail that the plans are not discriminatory and the plan be logically contradictory. To compare one of the standard to a plan that is contradictory is useless.
2.1. The positivist methodology

An approach to the methodology of science is generally known as Positivism, consists of instruments to read the “Book of Nature” [17,53]. Here top management grasps by experience or by some experiential-cognition process the correct plan to implement [6,45], and use may be made of well established mathematical methods or the case method. In positivism relations such as a price-demand schedule, a production cost element, which are technically unobservable, are generally assumed determinable directly without the need of complex experimental designs. Positivism was the principal paradigm considered in The Golden Age of Operational Research [31].

The basic postulates or axioms of this approach may be so stated:

(P1) An objective factual world exists and is accessible to the senses. Phenomena are perceptible and independent from experience.

(P2) Science can discover the true mechanisms of the real world to determine how matter of any type will behave or react if stimulated.

(P3) The scientific method is the set of empirical research procedures and the description of a phenomenon is an isomorphism of the real world at the chosen level of detail.

(P4) From research so conducted the mechanistic laws of the world and the Universe are obtainable.

Postulate (P1) asserts that all relationships are observable, independent from personal experience and therefore experts who refer to a fact do not have differing opinions or outcomes. If experience had a role in decision making opinions would have to be justified. Relationships underlying phenomena are determinable by postulate (P2). A model is formulable in the world of ideas, or on paper and then implemented by principle (P3). Finally by principle (P4) the solution formulated is correct, so positivism is discriminatory, and then implemented by principle (P4). Finally by principle (P4) the true mechanism may not be discernible.

If in a particular instance an expert has interpreted correctly the problem and its implementation happens to be correct, then interpretation of the phenomenon is isomorphic to the real world, but no validity can be attributed to the derivation, as only after the fact can the truth be ascertained so it would be purely anecdotal. Little confidence can be attributed to SCM plans based on positivism justifications. Moreover the positivist theory of knowledge is syntactically incorrect and semantically inadequate, as verified over two centuries ago [53].

To hold that facts are uncontroversial or objective and therefore independent of perception in SCM investigations may lead to logical contradictions as shown. Facts must therefore be interpreted and considered problematic so suitable estimation and specification procedures must be applied to formulate models and it will be necessary to verify that the representation is syntactically correct and semantically adequate.

2.2. The interpretative methodology

An exemplificatory theory of knowledge may be derived through science to avoid evident contradictions of the previous approach [1]. Sensations are fundamental to grasp relationships between phenomena. Through many representative exemplar applications a consensus may be built or a representative set of relationships can be proposed which will tend to a unique representation [53].

The interpretative approach is an idealist experimental or Neo-Kantian methodology, where expert knowledge and empirical research determine plausible formulations to improve plans [34], so holistic systems are often considered [31] leading to conditional non discriminatory plans, while survey experimental data analysis and simulation are applied to determine average tendential or representative behaviour. Thus canonical representations of phenomena are developed by these methods to yield possible ideal forms [16,53]:

(E1) The general form of the structure of sensations, are determined by considering similar scientific phenomena. The superficial or individual characteristics of sensations of a phenomenon are removed, to exhibit the underlying structure, not necessarily its actual structure.

(E2) The forms to be considered are ideal platonic structures.

(E3) The purpose of science is to discover these ideal structures or forms and the scientific laws which govern their relationships.

(E4) The scientific method is applied through experimental procedures, but common sense observations must be interpreted adequately by experts.

(E5) Theories are reinterpreted, modified and rendered more general, so increasing the content of the ideal forms in a theory while reducing the uninterpreted sensations.

Implementations cannot be proved correct, but the plausibility of an explanation, that is determining an ideal form, is accepted through a weight of evidence approach under the supervision of experts [43]. The principle of falsification [41] is analogous, as the contrapositive condition is enforced, rather than weighing favourable evidence, but neither are useful in the discrimination characterization of a plan which has been formulated [53]. The ideal form of a phenomenon could be pursued by studying sufficient instances, but the approach is limited, as only under strict
statistical survey principles the mathematical expectation of sufficient random instances will converge to a mean value or ideal form. Postulate (E1) states that ideal forms may be determined, but convergence should be proved. Moreover how can similar scientific phenomena (E1) be discerned? More fundamentally, dynamical systems could be analysed by ergodic theory under certain conditions [30]. If a process is stable and convergent then it can be considered an ideal form. However, if the structure imposed on the ideal form is plenastic, it coincides with the structure of sensations and both collapse to the positivist approach, [53]. Such is the case of simulation systems which are considered as ideal structures, but in almost all cases the implementations result plenastic [24,52]. In any case the conditions which ensure emergence of the ideal forms should be rendered explicit.

Sensations, personal and interpersonal comparisons could result to be invariant, because there may be an underlying common sense or consensus of experts so that the ideal form can be identified, but this must be demonstrated every time. To make the necessary comparisons and evaluations general statistical experimental design must be implemented, as discussed in Section 1. The Interpretative methodology, due to the peer knowledge assumptions (E1) and the reliance on perception of sensations, require that the elements of phenomena be tangible, real and observable. Thus ergodic theory, as limits of a trajectory, may not have the required properties and the presence of unobservable elements which affect phenomena must be denied in this approach, as the existence of the electron was denied [34], since they cannot contribute sensations nor can they belong to the ideal forms.

This approach turns out to be logically contradictory [53], sensations may not be observable even as limits of observation and interpersonal comparisons may result subjective, so it is mere opinion.

2.3. The instrumentalist methodology

The instrumentalist methodology is a formal neopositivistic approach to deduce theories and implement processes [20]. Models which are representative of phenomena are never considered ‘true’ or ‘verified’ but considered as instruments to ensure that the ex-ante events formulated are sufficiently similar to the ex-post events that occurs and the process is ‘discriminatory’. Moreover the functional forms and parameters of a model should not be assumed known or correct a priori, but must be inferred or estimated by formal methods so that the structure of the system determined is syntactically correct and results semantically adequate.

The version of Logical Positivism [53] considered here, is an instrumentalist version in which no realistic interpretation is presumed [17], and no theoretical relationship is posited between constructs and characteristics of the phenomenon. A rather cumbersome outline of the fundamental tenet of Instrumentalism is given to permit precise references in the sequel [40,53,17]:

(I.1) A logical calculus is specified and various sub-calculi are identified to permit derivations from the structures that will be defined.

(I.2) The extralogical terms are subdivided into two distinct classes:

(I.2.1) the dictionary of observable terms, to provide a description, as detailed as desired of the phenomenon,

(I.2.2) the dictionary of non observable or theoretical terms.

(I.3) Various languages can be defined and recognized by grouping appropriately the logical calculi and the dictionaries:

(I.3.1) a language of observable terms, composed of terms from the dictionary of observable terms only and certain primitive concepts, related through a specific logical calculus,

(I.3.2) a language of theoretical terms, composed of terms from the dictionary of theoretical terms only, related through a specific logical calculus,

(I.3.3) a residual language formed from relations among terms of both dictionaries.

(I.4) The aggregate language has a semantic interpretation which satisfies the following relationships:

(I.4.1) the domain of interpretation consists of concrete and observable terms,

(I.4.2) a partial interpretation of the theoretical terms and the propositions of the language which contains them, is derivable from two types of postulates:

(I.4.2.1) the theoretical postulates (the axioms of the theory) referred only to the dictionary of theoretical terms,

(I.4.2.2) the semantic postulates or correspondence rules consist of mixed propositions. These satisfy the following conditions:

(I.4.2.2.1) the set of correspondence rules is finite,

(I.4.2.2.2) the set of correspondence rules is logically compatible with the theory,

(I.4.2.2.3) the set of correspondence rules relating the two dictionaries contain at least one term from each.

The theory so specified is termed the reduction of a theory [53] and consists of the following elements and their relationships. A logical calculus and various sub-calculi (I.1) are explicitly defined to specify the operations that can be effected on the elements of the structure or on those adopted from other disciplines constituted from well formed calculi. The definition terms to be used in the analysis are indicated (I.2) where by (I.2.1) terms to be used to describe actual phenomena are specified, often indicated by a Standards and Methods manual. If these terms are not defined they are just sensations and the approach reverts to one of the former approaches considered. In (I.2.2) the theoretical dictionary of terms of the theory are defined and the specific theoretical properties are indicated. Accordingly, the syntactical correctness of an implementation will be considered within the theoretical dictionary, while its semantic adequacy will regard the observational dictionary, but relationships must be recognized through suitable language constructions to transform statements of one dictionary into statements of the other. So the importance of the languages indicated under postulate (I.3) is evident if precise results are desired and the specification of the languages should be carefully executed. Further postulate (I.4) and the subsequent principles limit the logical structure of this methodology so semantic propositions are finite (I.4.2.2.1), coherent (I.4.2.2.2) and explicit (I.4.2.2.3) and consequently the adequacy of semantic statements can be determined.

Given a theory which is syntactically correct and semantically adequate, the predictions (ex-ante) and the results (ex-post) of the phenomenon should coincide, within the limits of the precision imposed on the actual realization. If this is not so, then the initial and side conditions of the phenomenon or the relationships characterising the phenomenon must have changed. Every element can be checked by comparing the actual intermediate values to the analogous elements in the theory, which is the required discriminatory activity for plans. Thus a powerful diagnostic instrument is generated and once the elements which have caused the divergence have been identified, the theory can be corrected. Further as a plan is a derivation of a theory which is syntactically correct logical contradictions cannot occur, because of the principle of
excluded middle: either the axioms are coherent and the derivation is correct and therefore the implementation is correct or the axioms are incorrect and whether or not the derivation is correct is irrelevant and the implementation is wrong. For this reason ‘discriminatory’ plans are essential to determine as soon as possible that the axioms are incorrect and must be modified. Attentive implementations would also suggest the modifications to effect, if appropriate.

3. Demonstrably correct SCM systems

The aim of this section is to describe the implementation of demonstrably correct and sufficiently precise model through the instrumentalist methodology. The basic algorithm is specified and treated in detail elsewhere [20,19]. SCM phenomena must be modelled with the required detail by dated variables, expressed through short, noisy, nonlinear time series. The representation of a phenomenon by a static system will always constitute a special case of a dynamic representation and in its state space form can be given as [29]:

\[ x_t = f(x_{t-1}, u_t), \]
\[ y_t = h(x_t), \]

where \( y_t \in R^n \) is the vector of outputs at period \( t \), \( u_t \in R^n \) is the set of inputs at period \( t \) and \( x_t \in R^n \) is the state space vector at time \( t \), an intermediary or instrumental vector [35], defined as a theoretical term. An equivalent observation term cannot be defined, as technically the state space is unobservable, but in a suitable residual language indicated by postulate (1.3.3) an observable construction can be specified [48]. The time suffixes applied is standard notation in this field, [29] and states that the output vector at period \( t \) depends on the state-of the system at the same period. Sufficient historical data must be available from the management accounting system or other sources, to extract the required data flow, at the specified level of detail, and the various sets of variables indicated in the dictionaries. For dynamic nonlinear models the estimation space is not independent from the control space so to avoid suboptimization the determination of the values of the functional parameters and the control variables must be determined simultaneously.

The dynamic system is solved simultaneously for the functional form of the dynamic system, the optimal parameter estimates and the optimal plan by a suitably robust general constrained optimization algorithm such as S.O.C.R.A.T.E.S. (Simultaneous Optimal Control by Recursive and Adaptive Estimation Systems) [38], so consider the following optimization problem, [20]:

\[ \text{Min}\ J = \sum_{t \geq T} c(x_t, u_t, y_t), \]
\[ x_{t+1} = f(x_t, u_t, y_t), \]
\[ y_{t+1} = h(x_t, t), \]
\[ 0 \leq s(x_t, u_t, w_t, v_t), \]

where all variables are defined as above and (3) is the objective function to minimize general costs, over the prediction horizon \( (T+1, \mathcal{F}) \) or any other chosen merit function. The historical period, given by the interval \( (0, T) \) is known and will be used to determine with the prediction horizon the values of the parameters of the function proposed. The values of the parameters can change to ensure an optimal solution, but these values must satisfy the statistical properties over the historical period. Also (4) is the state transition subsystem and (5) is the output subsystem that must be determined. The inequality subsystem (6) consists of all the statistical conditions that must hold for \( w_t, v_t \), \( \forall t = 1, \ldots, T \) random residual variables. This ensures that the model estimated is a correct specification of the phenomenon, which avoids the difficulties and inconsistencies inherent in the estimation of models nonlinear in the parameters by the traditional methods [20]. To avoid the estimation from being biased due to a spurious interaction of the model specification and the sample [10], suitable subsystems are added to the constraints (6). Also to ensure that the optimal solution generated is a stable solution of the dynamic system an additional set of stability constraints can be added.

Feasible solutions to the optimization problem satisfy all the statistical properties imposed, so the parameter estimates result correct. By choosing more complex functional forms and increasing the number of control and state variables, better and better solutions will be obtained until a global minimum has been determined, if it exists. Thus, the simultaneous estimation and optimization problem can be solved [38,20]. The nonlinear dynamic model formulation allows to make use of all the results of Mathematical Systems Theory, which assure a syntactically correct specification of the phenomenon. The parameter estimates for the sequences of functional forms are efficient, asymptotically consistent and unbiased and so they are the best obtainable [20].

This approach produces discriminatory plans for the management systems considered, which result correct, as it can be proved, since the dictionary of observable terms is constituted of historical data and additions to the dictionary that have been made, through recursion of the model, until a sufficient verifiable precision is attained by postulate (1.2.1) and is part of the language of observable terms so defined and with the addition of certain primitive concepts as indicated in postulate (1.3.1). The dictionary of theoretical terms must also be constructed through the theoretical language adopted, by postulate (1.2.2), and the consequent language of theoretical terms, related through a specific logical calculus, defined through the modelling equations as indicated in postulate (1.3.2). Finally a residual language must be defined from relations in both dictionaries, which will include the necessary statistical conditions which can be included in postulate (1.3.3). Thus the semantic postulates or correspondence rules (1.4) which consist of mixed propositions determined through the solution of the aggregate language, S. O. C. R. A. t. E. S. will satisfy the model as, by construction, the solution is coherent with the historical data available, the optimal solution is stable and invariant to small perturbations [20] so this satisfies a ‘Certainty Equivalence’ solution [19]. If the solution is semantically adequate, and syntactically correct, which can be verified, so the plans will have the desired properties.

Suppose that through the positivist and interpretative methodologies and the application of peer knowledge and experience, a plan happens to be formulated which is not contradictory, considers the same objective as the plan of the instrumental formulation and satisfies all the constraints of the latter. Then the plan formed from the instrumentalist methodology will dominate or coincide with those formed from the other methodologies. If the positivist or interpretative methodologies are applied but some logical contradictions occur in the plan or the statistical conditions specified in the instrumentalist approach are not satisfied, then the plans may differ and those formulated by the first two approaches might appear to have better solutions, but these plans are in error as they lead to logical contradictions or one or more constraints may be violated or the plan may not satisfy the statistical properties [20].

4. Comparative implementations of SCM applications

Logical contradictions arise from particular methodologies because the axioms and hypotheses affirmed by experts in the formulation of SCM applications or operational plans, may be sophisms
and not verified so implementations are not satisfactory, as discussed in Section 2. To this end, two SCM applications will be examined regarding all three methodologies: a planning system for the management of a dynamical inventory system to control, the bullwhip effect, and the management plans to integrate collaborative SCM systems.

4.1. Bullwhip effect control plans

The “bullwhip effect” consists of fluctuations in the orders effected of a supplier compared to the sales enjoyed by the buyers and the distortion that will propagate upstream in accentuated form [32]. This phenomenon had been recognized early in dynamical linear systems and attributed to imprecision in the linear models proposed [24]. While various factors are assumed to affect the bullwhip effect [32], the most important factor considered is the results of demand signal processing effects, which will be the only aspect of concern here. The managerial policy pursued depends on observed demand by members of the chain most downstream (the retailer) and demand and supply amplification should be avoided [32,13] so multi-period inventory models are envisaged where demand is nonstationary over time and demand forecasts are updated over the leadtime period plus a safety stock [13,14,32].

4.1.1. Positivist management

The positivist methodology considered in (Section 2.1) is pertinent in many implementations, as the bullwhip effect is managed, presuming that the relevant aspects are perceptible, independent from experience (P1), (P3) and consist of the quantity demanded and the quantity delivered to the retailer per period, over a horizon, indicated as the demand at time t, as D and the model representation (P2), (P4) is isomorphical to the SCM process [13,14,32]. Further, the phenomenon is accessible to the senses and may be represented as a serially correlated autoregressive process (usually first order), given in the form:

\[ D_t = d + \rho D_{t-1} + u_t, \quad (7) \]

where \(|\rho| < 1\), \(u_t\) is an independent identically normally distributed random variable with mean 0 and variance \(\sigma^2\) and \(d, \rho\) are constants which satisfy the conditions indicated above [13]. These properties of the factual world (P1) are then used in the subsequent derivation both [13,14] for various forms of time series, in accordance with principle (P3). It is proved that the ratio of the variances of the ordered by the retailer to that of the demand faced by the retailer [13, Theorem 2.2, is greater than one, so the bullwhip effect occurs. Similar results have been derived [32]. However, the principle (P4) does not follow, since the derivation of the existence of the bullwhip is contradictory as the demand process, is assumed nonstationary, [32] while a time series must be at least stationary, to determine a solution consisting of a determinate bullwhip effect. With a nonstationary demand estimated accurately [14], the order-up-to point will be nonstationary so the optimal reorder points indicated by \((s, S)\), where \(s\) is the order quantity at time \(t\) and \(S\) is the order-up-to-point, will vary over time [32]. In particular, the mean and variance for non-stationary series may change over time and the latter may not even be defined. Thus the ratio of the two variances to indicate the existence of the bullwhip effect will generally be indeterminate. A contradiction entails, as this conclusion is contrary to the assertion. The correct policy for the process has been described, [14] but due to the traditional positivism methodology, the deep implications of such a result were not clarified.

For a stationary demand series, the optimal policy yields constant values of the reorder points [26], while if a leadtime occurs [32], then the least error forecast is the mean multiplied by the leadtime period, [18], which implies that no bullwhip effect is manifest, unless management errors occur.

4.1.2. The interpretative approach

The representation of decision processes by linear dynamical systems may be pursued through z-transform analysis and an equivalent optimal control approach [18]. By [Section 2.2, (E1)], sensations here have form and structure, so the bullwhip effect is perceived. The general form of the forecast for the nonstationary demand quantity \(n\) periods in the future, reflecting the accepted sensations of the retailer and supplier, is:

\[ \hat{D}_t = f(D_{t-1}, D_{t-2}, \ldots, D_{t-k}), \quad (8) \]

where \(D_t\) is the predicted demand at time \(T\) indicated in Eq. (7) and without loss of generality assume \(|\rho| > 1\) to ensure nonstationarity of the series. Then:

\[ \hat{D}_{t:n} = \hat{D}_t + \frac{\rho^2}{\rho^2 - 1} \sum_{i=0}^{n} \rho^i u_{t+i} \, \forall n \in T(t). \quad (9) \]

The process grows or oscillates without bound, so to restrict the phenomenon in a local neighbourhood it must be assumed that the nonstationarity of the demand process is mild and/or the leadtime \((v > 0)\) is small, so that \(\rho^2 + \rho - 2 < 1\) then the optimal order quantity, determined by the optimal control is a stationary process and will be determined from the last period’s demand of the customers. Periodically the order points will be recalculated in line with Section 2.2 [point (E5)]. By considering linear models the bullwhip effect can be avoided and stable reorder policies enacted [18] adopting eventually a smoothing inventory policy, but this leads to a contradiction since the bullwhip effect can be avoided in general, while sensations indicate the opposite. Hence no ideal form exists and sensations are imprecise, as concluded a long time ago [24].

4.1.3. The instrumentalist methodology

An optimal control of the dynamic nonlinear representation of the supply chain is considered, [19], based on historical data sets of the relevant input–output realizations. Whether the series is nonstationary or not, the constraints specified ensure that the mean of the residuals is zero and the variance of the residuals is small and constant in time, by absorbing all the eventual systematic nonstationary fluctuations of the process in the dynamical system formulation. The nonlinear demand for the product must be determined at every period, for a certain number of periods in the future, so that the optimal dynamic order policy can be calculated. As the residuals of the demand process will have a constant variance, and the solution is homoscedastic, the optimal reorder points can be determined, depending on the costs of procurement and inventory and the predicted demand and residual variance, in the transformed space and the management plan can be implemented with ease. To conclude the bullwhip effect can be suppressed by accurate management and the results are derived deductively from the postulates of this approach and verified through experimental implementations. These results show that the assumed traditional approaches are wrong: whether the quantity demanded and the quantity delivered give rise to stationary or nonstationary series, then the bullwhip effect can be managed and the effect will occur only if mistakes are made in its management. This was also the conclusion indicated [24].

4.1.4. Extensions to the beer-game

The beer-game is often qualified as a “decision making tool” and is used as a simulation didactic game during the formation of managers to handle the dynamical management of demand and supply of consumer products. Experience in the beer-game [52] has rarely confirmed that the players first verify whether demand and supply for the product is stationary or nonstationary and then enact the appropriate policy as indicated above. In fact given a finite time
Collaborative policies are difficult to manage, as presented in Section 2.2, and require the integration of the New Welfare Economics. If the equilibrium point is stable, this can be enforced through an algorithm for decision processes to determine the optimal SCM plans. The required conditions to check if an equilibrium point is stable are straightforward; however, the observable demand and the supply curves in the neighborhood of such a point are more complex to determine. Further, such a system may be stable to price adjustments and unstable to quantity adjustments or vice versa. However, equilibrium points may be indeterminate or nonexistent. Peer knowledge of managers or their structure of sensations, without a formal modeling approach forming anecdotal evidence, may lead to the pursuit of the false goal or logical contradictions.

4.2. Collaborative SCM system

The aim of collaborative management in formulating SCM plans is to determine supply and demand equilibrium over time to make all the participants better off and none worse off [22], often through revenue sharing contracts, but compensatory conditions of the New Welfare Economics must be satisfied [33], although it has been hardly ever considered in this field.

Collaboration can be applied in a rolling schedule environment and multi-tier SCM comprising several buyers and/or suppliers. Team behavior of the partners may occur, nevertheless the negotiation process can be applied to loose relationships where self-interest and opportunistic behavior occurs. General guidelines to form strategic collaboration supply chains and frameworks for collaborative planning have been formulated, but the feasibility of the proposals must be ascertained, over the planning horizon, before trying to determine the savings that can be generated [50]. Compromise solution cannot be established a priori, without carrying out complete negotiations.

4.2.3. Instrumentalist methodology

In the instrumentalist approach, a collaborative plan can be formulated with dynamic and nonlinear models and stochastic disturbances can also be considered, so that buyers and suppliers may use algorithms for decision processes to formulate optimal SCM plans [19]. Here the offers of the partners are evaluated by each member of the group running a personal version of the algorithm with the additional price-quantity alternative demanded. The evaluation of this policy will determine if the request can be accepted by all to the advantage of each or whether a tâtonnement process between multiple iterations of the algorithm by each partner should be pursued. Suppliers may decide to collaborate to the extent of placing all their resources in common, so a multi-stage supply chain production program could be envisaged or a multi-objective approach may be applied with an agreed subdivision of the additional accruing profits. The implementation indicated can be shown to syntactically correct and semantically adequate [19].

5. Conclusions

Expert opinion, experience, intuition, anecdotal formulations are enticing aspects in the formulation of decision making and in knowledge acquisition methodologies to formulate SCM operational plans. The activities to enact those specified in the plans would be satisfactory if the axioms that define the methodologies are correct and the derivation of the relationships and parameters have been assigned correctly. In this case, as was concluded in Section 3, under an appropriate methodological formulation, the ex-ante plan formulated will converge to ex-post realization.

Positivist and interpretative methodologies have long been considered basic paradigms of the scientific method [53], but are now unacceptable, as they lead to logical contradictions, since the premises formulated may be either invalid or more generally be mutually dependent and give rise to contradictions, see Section 2. If the axioms do not hold or if the assignment of the relations and parameters considered are faulty or if some unpredictable effect has occurred the ex-ante and ex-post formulations will differ. In these circumstances either the axioms must be modified or the observational and assignment method of the underlying structure must be adapted or, also, the data available must be integrated with the new structure. The possibility of expressing new formulations of the axioms indicated in Section 2.1 or in Section 2.2 will require modifications in the methodologies, to ensure that “... An objective factual world exists and is accessible to the senses. Phenomena are perceptible and independent from experience...” (P1). Also concordant modifications may not exist, so a different methodology would have to be adopted, but how can it be ascertained? Obviously, under these circumstances, the approach collapses and cannot be adapted or redefined as the logic of the conditional will have to be considered. Thus any new formulation of the basic axioms contradicts the very axioms asserted as valid or true.
If the axioms of an interpretative methodology must be changed, the ideal forms must be modified and sensations are no longer pertinent. The maintenance of a positivist or an interpretative methodology may result in logical contradictions since from a given premise a conclusion (the plan) and its opposite could result, as discussed in Section 1 and 2 in the instrumentalist methodology, plans are formulated as instruments to ensure that the ex-ante events formulated are sufficiently similar to the ex-post events by applying a Data Driven approach of continuous reformulations so as to ensure that the process is ‘discriminatory’, while in the other methodologies a theory driven approach is required since the plan should be true and verifiable, as discussed in Section 3.

Traditional SCM methodologies were apparently enacted in developing plans for Enron [11], General Motors [25] and IBM [8]. For the first two cases wrong decisions were made, as logical contradictions occurred but were not recognised in time since the plans enacted were not ‘discriminatory’, as otherwise management would have taken remedies. Plans at IBM were continuously revised and their effects on plans were assessed, so a ‘discriminatory’ approach was applied, even if the complete instrumental methodology may not have been implemented, nevertheless part of this approach had been enacted to manage plans successfully in the ‘discriminatory’ fashion.

Adherence to positivist or interpretative approaches may lead to read the wrong ‘Book of Nature’ and the wrong paragraph of the tome and it can be shown that ‘discriminatory’ plans formulated by an instrumental methodology dominate the other implementations, see Section 3. This arises because the assumptions, intuitive or anecdotal, formulated in the traditional approaches and the implementations discussed in Section 4 may result incomplete or faulty. In theory driven approaches, it is necessary not to modify the formulations, so logical contradictions ensue, see Section 4.1 or the “factual world” is considered in a too simplified fashion, so the premises are dependent and simplistic and so logical contradictions arise, see Section 4.2. The major limitations of the traditional methodologies is that inputs and outputs are regarded as directly observable by experts and comparisons among these entities may be evaluated without effecting appropriate experimental designs to ensure that the ‘ceteribus paribus’ hypotheses in all comparisons are respected. Traditional methodologies consequently are generally unacceptable, but resolving the problem of observability by pursuing appropriate experimental results would contradict the traditional methodological formulations.

Different management methodologies may alter the accuracy of operational SCM plans, but when these have been formulated correctly, the plan implemented by the instrumental methodology will dominate the results of the other plans formulations [20].

Acknowledgement

The authors would like to thank warmly the excellent work carried out by the Editor and two anonymous referees who though suggested modifications and different perspectives have improved greatly the logical syntactical and semantical structure of the paper. The importance of editors and referees can never be underestimated. Any final errors of omission and significance must be considered completely the fault of the authors.

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