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**The theory of constraints and the constraints of theory:
A structural equation model for supply chain disruptions**

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ABSTRACT

A model is presented, whose constructs represent factors related to manufacturing supply chain disruption. The primary questions motivating the model's formulation concern the influence that use of the Theory of Constraints (TOC) in manufacturing management may have on supply chain disturbance handling. Using data from 165 plant participants in the high performance manufacturing (HPM) research project, the model's measurement characteristics were validated through confirmatory factor analysis. Path analysis of the model then showed that TOC orientations among managers have a positive influence on perceived supply chain disruption-discovery success, as do JIT relationships with plant customers. The model's significant paths also show that customer JIT and TOC orientation of managers together explain 51% of the variation in respondents' evaluations of their plants' daily task performance success. TOC thinking also has a positive influence on overall plant performance in the perceptions of managers. Interestingly, the supplier JIT construct showed no significant explanatory role in the model.

INTRODUCTION

Supply chain research and writing of the recent past has begun to show an increasing interest in the notion of supply chain disruption. As expressed by several authors, the notion refers to local failure within a global network of suppliers, producers, distributors, and customers (Hendricks and Singhal, 2005b). Supply chain disruptions have sometimes been called "blips" (Anonymous, 2005) and often reflect the fact that supply chain networks are equally dependent on further components, such as transporters, ports, warehouses, and retailers (Chopra and Meindl, 2004). Disruptions in a supply chain network can manifest themselves in many ways. Such phenomena as transportation delays, port stoppages, accidents and natural disasters, part shortages, changing customer requirements, quality problems, production problems, and strikes can all disturb the flow of material through a complex supply chain (Blackhurst et al., 2005; Hendricks and Singhal, 2005b; Juettner, Peck and Christopher, 2003).

While local disturbances such as these may seem small compared to the global context of their overall supply chain networks, current literature has now begun to vividly expose the devastating effects they can have on those networks. Their ripple effects can lead to "havoc" for a supply chain's participants (Anonymous, 2004) and even shake the very foundations of their firms (Hendricks and Singhal, 2005b). Indeed, the well-known phenomenon called the bullwhip effect offers a dramatic illustration of supply chain disruption consequences (Lee, Padmanabhan and Whang, 1997). The chaos of over-reactions, unnecessary interventions, second-guessing, mistrust, and distorted information can turn a small disturbance into a major crisis (Juettner, Peck and Christopher, 2003).

Disruptions have become an inevitable fact of life for managers concerned with supply chain issues. They have been referred to as "everyday" occurrences (Hendricks and Singhal, 2005b) and have been blamed for consuming one third to half the time of buyers, material managers, and purchasing agents with efforts to resolve them (Anonymous, 2004). This ubiquitous influence on the functioning of supply chains has clearly been attributed to increased vulnerability caused by the growing complexity of today's supply chain networks. Blackhurst and colleagues (2005) cite "inter-related trends" of current practice, which include a rise in global sourcing and a move towards increased responsiveness with lower inventory levels. Blackhurst et al. (2004) note that each of the supply chain members may also belong to other

supply chains, which removes any guarantee that all supply chain members share in common objectives. Indeed, a trend to outsourcing at every level can exacerbate this circumstance, with conflicting goals being the result (Juettner, Peck and Christopher, 2003).

The costs of supply chain disruption are also enjoying increasing attention in research and writing. Their significance has been elucidated in general terms and in specific investigations. A growing body of work by Hendricks and Senghal, for example, has succeeded in tracking the effects of supply chain disruptions on the long-term stock prices and equity risks of major firms (2003, 2005a, 2005b). This reflects a renewed orientation to supply chain risk analysis and contingency planning. A previous priority of cost minimization in supply chain design is now giving way in the literature to a strong admonition for assessment of vulnerability and the cost trade-offs evinced by concentrated supply chain continuity planning (Anonymous, 2003; Christopher, 2005; Blackhurst et al., 2005; Juettner, Peck and Christopher, 2003).

Mitigation of supply chain disruptions is of course a major goal in many expositions of the notion. Several approaches have been forwarded, which seek to engender advanced preparation for these disturbances, and many advocate the prerequisite conditions of visibility and collaboration along the entire supply chain network. (See, for instance, Anonymous, 2003, Hendricks and Singhal, 2005b, or Juettner, Peck and Christopher, 2003.) This general call for supply chain information-sharing and cooperation has always been a standard feature of much of the literature on supply chain modelling (Blackhurst, Wu and O'Grady, 2004; Boyaci and Gallego, 2004; Cachon and Fisher, 2000) and one important presumption has pervaded all of this work. It is always required that approaches and tools are available for reliable, timely, and sound analysis of supply chain performance data. Some important components of this requirement have been nicely elucidated by Blackhurst and colleagues in 2005. Whether it be for cost analysis, forecasting, or dynamic control, the monitoring that supply chain visibility enables must always be accompanied by a core element of data analysis and management decision-making support.

A myriad of philosophies and approaches have been developed over the years for driving the data analysis and decision-making support in manufacturing management itself. Such theories as material requirements planning (MRP), manufacturing resource planning (MRP II), just in time (JIT), and enterprise resource planning (ERP) have all reflected particular views of the manufacturing environment and the way the environment's performance data should be used to manage the processes involved. Many of these methods for manufacturing management and control have influenced aspects of their firms' functioning that might be seen as peripheral to the production processes themselves. In particular, the supply chain networks of most manufacturing firms have been strongly influenced by the approaches these firms take to defining and controlling their throughput aspirations. Whether these management approaches include the explicit intentions of governing the supply chain or simply exert their influence on it by a spill-over effect, it is reasonable to assume they might additionally impact the incidence of and reactions to supply chain disruptions.

One approach to the management of production processes, which has received nontrivial treatment in recent years, is the theory of constraints (TOC). Proposed and developed by Eli Goldratt (Goldratt and Cox, 1984), this theory prescribes the concerted attention of manufacturing management on the individual processes that constitute the primary constraints, or "bottlenecks," to achieving the goals of production. Nice synopses of this theory and its implementation methods can be found in Berry and Smith (2005) or Blackstone (2001). It, too, can strongly influence the functioning of a supply chain network when it is applied to the management of production priorities in a manufacturing firm. Indeed, there have been several

works that advocate the explicit use of TOC in efforts to design and manage supply chain functions (Belvedere and Grando, 2005; Blackstone, 2001; Hugos, 2003). It is the goal of the work associated with this paper, to discover the degree to which a management orientation to TOC may influence a manufacturing firm's approach to dealing with supply chain disruptions.

The following section establishes arguments for the relevance of certain individual factors in characterizing the circumstances surrounding supply chain disruptions. After that, a section of the paper describes the methodology used in this research for capturing and measuring essential elements of these factors. It delineates the hypotheses, with which the research started, and an initial approach to formulation of the research model, using principle components factor analysis. A following section elucidates the results of model respecification and validation, performed with confirmatory factor analysis, and path analysis, done with the resulting structural equation model. A concluding section contains a discussion of the results, their limitations, and the need they reflect for further work in the area.

FACTORS RELEVANT TO SUPPLY CHAIN DISRUPTION

Considerable discussion in the literature of supply chain disruptions seems to draw on the increasing complexity of today's supply chain networks and the precise requirements this places on each supply chain participant. Most authors conclude that this raises the vulnerability of supply chains to disruptive occurrences (Blackhurst, Wu and O'Grady, 2004; Blackhurst et al., 2005; Juettner, Peck and Christopher, 2003). While these disruptions now have a myriad of potential sources in current global supply chains, it is reasonable to expect that they will be discovered through the regular, real-time monitoring of a firm's local processes. Indeed, it might even be expected that actual production issues can be reflective of supply chain problems (Blackhurst et al., 2005). It was therefore postulated that indications of a firm's efforts to monitor its supply chains, together with its ability to maintain desired schedules in its daily production, will provide some signal to the firm's disruption handling efforts.

Of course relationships with suppliers can provide important insights into a firm's prospects for supply chain success. In fact, some writers of practitioner pieces give suppliers the primary blame for supply chain disruptions when they occur (Anonymous, 2003; Anonymous, 2005). The financial solvency of suppliers and their dependability in the face of goals that may conflict with a client firm's needs always represent a degree of risk, with which manufacturing firms must contend (Hendricks and Singhal, 2005b). It is reasonable to expect that suppliers who can invest in and reliably maintain JIT delivery relationships with a manufacturing firm probably reflect encouraging aspects of that firm's supply chain functioning. The visibility and cooperation that such relationships may imply constitute "a core element" of supply chain disruption avoidance and mitigation (Blackhurst et al., 2005). It was postulated here that indicators of supplier relations, JIT specifically and cooperativeness in general, will evince important signs of a manufacturing firm's supply chain disruption experience.

Customer relationships constitute a significant influence on a firm's evaluation of its own success in production industries. An interesting discussion of this situation in the process industries, for example, was forwarded by Belvedere and Grando in 2005. Blackstone (2001) has emphasized the importance of customer-manufacturer cooperation in dealing with supply chain issues, while noting the difficulties that can surface in that connection when customer JIT processes are implemented. With an emphasis on what Blackhurst and colleagues call "reachability analysis" (2005), the downstream directions in a supply chain are given strong priority in approaches recommended for recovery from supply chain disruptions. It is intended

that measures of customer JIT implementation shall serve in this research as an indicator of the cooperation a manufacturing firm experiences with its downstream supply chain partners. It was hypothesized that such measures will show relevance to indicators of supply chain disruption handling.

Some work that has been published on the application of the theory of constraints to supply chain management has asserted that one constraint (or “bottleneck” in the sense of TOC) in every supply chain is the demand for a firm’s production output. Hence, synchronizing the supply chain’s participants to the market’s demand for a product can go a long way towards minimizing the disruptions experienced in the supply chain (Hugos, 2003). Since the investigation described here was intended to explore the connections between a TOC orientation and the management of supply chain disruptions, it was decided to include indicators of demand stability and competitive intensity in the analysis. It was thought that the indications they provide about demand uncertainty would show relation to the propensities of firms to handle disruptions well.

METHODOLOGY AND RESULTS

Indicator items for the factors discussed above were selected from the database that was assembled in conjunction with the High Performance Manufacturing (HPM) research project. This project evinced the collection of quantitative and qualitative performance data about 189 manufacturing plants from the machinery, electronics, and automotive supply industries in the U.S., Japan, Germany, Sweden, Finland, and Korea. Data were compiled for each plant from the responses of 23 individuals from various levels in the plant hierarchy and all major functional areas. Responses were aggregated for each plant and constituted multiple indicators of insight about the areas of information systems/information technology, environment, goals, human resources, improvement, just-in-time/TOC, quality, strategy, technology/mass customization, maintenance, new product development, and supply chain. The indicators used in this research were qualitative ones, measured with Likert-type scales and reflecting perceptions of managerial personnel about their topics.

Table 1 lists the indicators selected, together with their hypothesized factor groupings. With each item, the table shows the corresponding record key in boldface for comparison with subsequent steps of the analysis. In addition to factors discussed above, an overall time performance factor was included.

Table 1. Hypothesized Factor Groupings

Supplier Relations	
pstrn01	We are comfortable sharing problems with our suppliers.
pstrn02	In dealing with our suppliers, we are willing to change assumptions, in order to find more effective solutions.
pstrn03	We believe that cooperating with our suppliers is beneficial.
pstrn04	We emphasize openness of communications in collaborating with our suppliers.
psspn06	We share our production plans with our suppliers.
Theory of Constraints	
jstcn01	We consistently monitor work-in-process in front of each process to identify the bottleneck (constraint) in the
jstcn02	We make every effort to minimize or eliminate idle time of the bottleneck process.
jstcn03	We control non-bottleneck processes' levels of utilization and timing of the order release by taking into account the capacity of the bottleneck process.
jstcn04	We consistently make efforts to increase the capacity of the bottleneck process.
jstcn05	We assign parts to be processed in the bottleneck process by identifying those with the earliest due dates.
jstcn06	We make sure that only good parts are processed through the bottleneck process.
jstcn07	We consider an hour lost in the bottleneck process as an hour lost for the whole plant.
jstcn08	We balance the flow of products through the production facility, rather than balancing the capacities of the
Supplier JIT	
jsvnn01	Our suppliers deliver to us on a just-in-time basis.
jsvnn02	We receive daily shipments from most suppliers.
jsvnn09	We can depend upon on-time delivery from our suppliers.
jsvnn10	Our suppliers are linked with us by a pull system.
jsvnn11	Suppliers frequently deliver materials to us.
Customer JIT	
jsvcn01	Our customers receive just-in-time deliveries from us.
jsvcn02	Most of our customers receive frequent shipments from us.
jsvcn04	We always deliver on time to our customers.
jsvcn05	We can adapt our production schedule to sudden production stoppages by our customers.
jsvcn06	Our customers have a pull type link with us.
jsvcn07	Our customers are linked with us via JIT systems.
SC Disruption Handling	
jssyn03	We can easily determine bottleneck operations in our supply chain.
jsftn03	We usually meet the production schedule each day.
jsftn06	We usually complete our daily schedule as planned.
psspn02	We consider our customers' forecasts in our supply chain planning.
psspn04	We monitor the performance of members of our supply chains, in order to adjust supply chain plans.
psspn05	We gather indicators of supply chain performance.
Time Performance	
grcpn03t	- On time delivery performance
grcpn04t	- Fast delivery
grcpn08t	- Cycle time (from raw materials to inventory)
Demand Stability	
pssdn01	Sales and manufacturing personnel communicate well with each other in this organization.
pssdn02	Manufacturing demands are stable in our firm.
pssdn04	Our total demand, across all products, is relatively stable.
Competitive Intensity	
ssmin01	We are in a highly competitive industry.
ssmin02	When our competitors make a move, we are forced to quickly follow it.
ssmin03	Our competitive pressures are extremely high.

After culling cases with missing values, a set of 165 subject firms was established. The data were first examined for the presence of a factor structure which resembles the constructs postulated. A principle component (exploratory) factor analysis was performed, using varimax rotation and fairly standard cutoff values of 1.0 for eigenvalues and 0.5 for factor loading.

Table 2. Rotated Component Matrix

(Varimax rotation with Kaiser Normalization - 20 iterations.)

	Component									
	1	2	3	4	5	6	7	8	9	10
pstrn01 We are comfortable sharing problems with our suppliers.	0.832	0.159	-0.021	0.133	0.014	0.191	-0.020	-0.126	-0.020	-0.073
pstrn03 We believe that cooperating with our suppliers is beneficial.	0.763	0.018	0.080	0.136	0.058	-0.023	0.019	-0.107	0.114	-0.027
pstrn04 We emphasize openness of communications in collaborating with our suppliers.	0.756	-0.007	0.269	0.106	-0.127	-0.167	-0.078	0.063	0.140	-0.078
pssp05 We gather indicators of supply chain performance.	0.664	0.206	0.094	-0.097	0.112	0.383	0.003	-0.174	0.098	-0.170
pstrn02 In dealing with our suppliers, we are willing to change assumptions, in order to find more effective solutions.	0.553	0.123	-0.028	0.168	0.014	0.323	0.225	0.159	-0.167	0.107
jstcn01 We consistently monitor work-in-process in front of each process to identify the bottleneck (constraint) in the production system.	-0.042	0.615	0.157	0.238	0.153	0.352	0.103	0.000	0.090	0.103
jstcn02 We make every effort to minimize or eliminate idle time of the bottleneck process.	0.158	0.655	0.390	0.182	-0.003	0.112	0.034	0.030	0.094	0.044
jstcn03 We control non-bottleneck processes' levels of utilization and timing of the order release by taking into account the capacity of the bottleneck process.	-0.010	0.663	0.333	0.131	-0.001	0.165	0.175	0.058	0.124	-0.048
jstcn04 We consistently make efforts to increase the capacity of the bottleneck process.	0.085	0.729	0.146	0.204	0.146	-0.028	0.002	0.301	0.095	0.124
jstcn05 We assign parts to be processed in the bottleneck process by identifying those with the earliest due dates.	0.016	0.569	0.308	-0.021	-0.026	0.357	0.023	-0.073	-0.173	0.018
jstcn07 We consider an hour lost in the bottleneck process as an hour lost for the whole plant.	0.352	0.675	-0.157	-0.105	0.192	-0.066	0.022	0.098	0.055	-0.033
jsftn03 We usually meet the production schedule each day.	-0.031	0.296	0.736	0.181	0.221	0.170	0.065	0.205	0.073	0.016
jsftn06 We usually complete our daily schedule as planned.	0.181	0.156	0.736	0.051	0.178	0.178	0.079	0.262	0.057	-0.123
jsvcn04 We always deliver on time to our customers.	0.094	0.136	0.728	0.096	0.115	-0.118	0.320	0.048	-0.038	0.008
jsvnn09 We can depend upon on-time delivery from our suppliers.	0.098	0.227	0.603	0.362	0.110	0.228	0.005	0.102	0.009	0.015
jsvnn02 We receive daily shipments from most suppliers.	0.024	0.143	0.105	0.755	0.173	0.029	0.128	-0.003	0.040	0.089
jsvnn01 Our suppliers deliver to us on a just-in-time basis.	0.297	-0.050	0.316	0.652	0.259	0.147	0.035	0.058	-0.025	-0.103
jsvnn11 Suppliers frequently deliver materials to us.	0.060	0.336	-0.003	0.647	-0.022	0.213	0.257	0.089	0.024	-0.265
pssp06 We share our production plans with our suppliers.	0.330	0.049	0.157	0.616	0.105	-0.218	-0.023	0.158	-0.063	0.111
jsvcn01 Our customers receive just-in-time deliveries from us.	0.092	0.004	0.400	0.297	0.711	-0.047	0.050	-0.025	-0.083	0.119
jsvcn06 Our customers have a pull type link with us.	-0.029	0.183	0.106	0.321	0.678	0.284	-0.033	0.127	0.081	0.027
jsvcn02 Most of our customers receive frequent shipments from us.	-0.009	0.196	-0.001	-0.078	0.648	0.017	-0.063	0.336	0.162	-0.255
jsvcn07 Our customers are linked with us via JIT systems.	0.021	0.065	0.378	0.467	0.639	0.134	0.037	0.016	0.044	0.045
pssp02 We consider our customers' forecasts in our supply chain planning.	0.460	0.338	0.087	0.114	0.488	-0.070	0.162	0.050	-0.140	0.086
jstcn06 We make sure that only good parts are processed through the bottleneck process.	0.110	0.312	0.271	0.011	-0.069	0.629	0.032	0.143	0.053	0.322
pssp04 We monitor the performance of members of our supply chains, in order to adjust supply chain plans.	0.481	0.115	0.059	0.058	0.299	0.588	0.162	-0.064	-0.025	-0.028
jsvnn10 Our suppliers are linked with us by a pull system.	0.035	0.177	0.201	0.461	0.124	0.525	-0.046	0.119	0.188	-0.150
jssyn03 We can easily determine bottleneck operations in our supply chain.	0.260	0.464	0.124	0.059	0.267	0.435	-0.155	-0.029	-0.106	-0.021
grcpn03t - On time delivery performance	0.079	0.109	0.179	0.056	0.117	-0.055	0.827	0.122	-0.051	-0.022
grcpn04t - Fast delivery	0.026	-0.044	0.121	0.055	-0.019	0.038	0.833	-0.071	-0.086	0.087
grcpn08t - Cycle time (from raw materials to inventory)	-0.069	0.195	0.054	0.223	-0.183	0.210	0.537	0.079	0.143	-0.305
pssdn04 Our total demand, across all products, is relatively stable.	-0.105	0.073	0.210	0.079	0.086	-0.013	-0.034	0.861	-0.135	-0.040
pssdn02 Manufacturing demands are stable in our firm.	-0.125	0.127	0.145	0.133	0.143	0.081	0.123	0.808	-0.209	0.094
ssmin01 We are in a highly competitive industry.	0.089	0.049	0.002	0.029	0.055	-0.078	-0.018	-0.128	0.849	-0.023
ssmin03 Our competitive pressures are extremely high.	0.045	0.142	0.053	0.040	0.025	0.178	-0.073	-0.163	0.784	0.318
ssmin02 When our competitors make a move, we are forced to quickly follow it.	-0.164	0.085	-0.033	-0.037	-0.018	0.086	-0.017	0.058	0.206	0.783
pssdn01 Sales and manufacturing personnel communicate well with each other in this organization.	0.349	0.275	0.399	0.185	0.036	0.248	0.115	-0.093	-0.167	0.019
jsvcn05 We can adapt our production schedule to sudden production stoppages by our customers.	0.248	0.145	0.348	-0.004	0.082	0.321	0.187	0.316	0.143	0.101
jstcn08 We balance the flow of products through the production facility, rather than balancing the capacities of the processes.	-0.346	0.152	-0.045	0.150	-0.328	-0.048	0.010	-0.041	-0.263	0.294

As shown in the factor loadings of Table 2, 35 of the original 39 items loaded on 9 discrete factors with two or more indicators. While the 8 originally postulated constructs achieved

validation in this analysis, several items loaded strongly with other factors than had been postulated. In two cases, cross loadings of items were evident and theoretical considerations surrounding their content were used to decide on their appropriate positioning within the factor structure. In addition, a ninth factor (component 3) appears to have been established, whose items relate to the daily operations of the subject firms.

It is interesting to note that component 6, originally conceived to measure supply chain disruption handling, only retained items associated with establishing the circumstances of such disruptions. This seems to instantiate a distinction that was drawn by Blackhurst and colleagues in 2005. In a cogent breakdown of the issues relevant to research on this topic, they proposed that separate focus be placed on the areas of disruption discovery, disruption recovery, and supply-chain redesign. Factor 6 appears to represent the managers' perceptions of a subject firm's mechanisms for discovering supply chain disruptions in a timely manner. Since the HPM database was otherwise devoid of specific indicators for this phenomenon, it was decided to focus the subsequent analysis on supply chain disruption discovery.

Table 3 shows descriptive statistics for the 9 factors, as well as Cronbach alpha values for their factor item groupings. All of the alpha values are above 0.693, indicating reliable constructs for this exploratory research (Nunnally, 1978). Table 4 shows correlations computed for the constructs.

Table 3. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Cronbach Alpha
1 Supplier Relations	165	4.13	6.68	5.47	0.523	0.810
2 Theory of Constraints	165	2.39	6.90	5.09	0.650	0.821
3 Daily Operations	165	2.58	6.50	5.04	0.759	0.842
4 Supplier JIT	165	2.67	6.38	4.63	0.816	0.753
5 Customer JIT	165	2.56	6.28	4.66	0.816	0.809
6 SC Disruption Discovery	165	2.42	6.55	4.76	0.664	0.706
7 Time Performance	165	2.50	7.00	5.05	0.969	0.693
8 Demand Stability	165	1.33	5.83	3.89	1.083	0.857
9 Competitive Intensity	165	3.17	7.00	6.06	0.777	0.766

Table 4. Pearson Correlations

	Supplier Relations	Theory of Constraints	Daily Operations	Supplier JIT	Customer JIT	SC Disruption Discovery	Time Performance	Demand Stability	Competitive Intensity
Supplier Relations	1	0.332**	0.270**	0.343**	0.236**	0.494**	0.118	-0.124	0.126
Theory of Constraints	0.332**	1	0.551**	0.376**	0.412**	0.629**	0.246**	0.237**	0.165*
Daily Operations	0.270**	0.551**	1	0.487**	0.539**	0.517**	0.329**	0.383**	0.070
Supplier JIT	0.343**	0.376**	0.487**	1	0.525**	0.417**	0.278**	0.236**	0.050
Customer JIT	0.236**	0.412**	0.539**	0.525**	1	0.466**	0.129	0.303**	0.089
SC Disruption Discovery	0.494**	0.629**	0.517**	0.417**	0.466**	1	0.165*	0.183*	0.160*
Time Performance	0.118	0.246**	0.329**	0.278**	0.129	0.165*	1	0.150	-0.054
Demand Stability	-0.124	0.237**	0.383**	0.236**	0.303**	0.183*	0.150	1	-0.236**
Competitive Intensity	0.126	0.165*	0.070	0.050	0.089	0.160*	-0.054	-0.236**	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

With the discriminant validity and reliability of the model's constructs having been established, the next step of analysis was to test for the unidimensionality of the model's indicators and constructs, using confirmatory factor analysis (CFA). Unidimensionality refers to an item's tendency to *only* measure that for which it was intended, without exhibiting cross-

correlational patterns with other components of the model. The CFA approach not only measures unidimensionality of the model's factors, but also identifies specific redundancies among the components. This allows redundant items to be dropped from the model, thus improving the unidimensionality. Identifying and removing such items leads to a more consistent and parsimonious instrument (Bagozzi and Fornell, 1982). Unidimensionality *cannot* be measured with the PCA technique for exploratory factor analysis or by assessing the Cronbach alpha reliability statistics of alternatively represented models (Segars, 1997). CFA is part of the structural equation modeling (SEM) approach to data analysis.

Following a standard approach to CFA (Segars and Grover, 1993), the model was evaluated for unidimensionality. The AMOS 5.0 structural equation modeling program was used for this (Arbuckle, 2003). The CFA iterative process involved dropping items from the model, one at a time, which (in successive CFA runs) showed high cross-correlation with other items or with model factors, or which shared high residual variance with other items of the model. At each stage of this process, deletion of an item occurred if the modification index (a measure of cross-correlation) was greater than the critical threshold of 5.0 (Segars, 1997) or if a value was greater than 2.58 in the standardized residual covariance matrix (Segars and Grover, 1993). The theory underlying the component in question was considered before eliminating it, in order to insure that the final measurement of the model's factors would not omit any notions that are central to the study's goals.

Table 5. CFA Results

	Factor Loadings	Cronbach Alpha
Theory of Constraints		0.706
jstcn02 We make every effort to minimize or eliminate idle time of the bottleneck process.	0.792	
jstcn03 We control non-bottleneck processes' levels of utilization and timing of the order release by taking into account the capacity of the bottleneck process.	0.720	
Daily Operations		0.880
jsftn03 We usually meet the production schedule each day.	0.945	
jsftn06 We usually complete our daily schedule as planned.	0.831	
Supplier JIT		0.719
jsvnn01 Our suppliers deliver to us on a just-in-time basis.	0.805	
jsvnn02 We receive daily shipments from most suppliers.	0.669	
psspn06 We share our production plans with our suppliers.	0.571	
Customer JIT		0.798
jsvcn06 Our customers have a pull type link with us.	0.710	
jsvcn07 Our customers are linked with us via JIT systems.	0.935	
SC Disruption Discovery		0.619
jssyn03 We can easily determine bottleneck operations in our supply chain.	0.736	
psspn04 We monitor the performance of members of our supply chains, in order to adjust supply chain plans.	0.615	
Time Performance		0.529
grcpn03t - On time delivery performance	0.604	
grcpn08t - Cycle time (from raw materials to inventory)	0.599	

Table 5 shows the final model resulting from confirmatory factor analysis, together with standardized factor loadings and Cronbach reliability statistics. The measurement model was reduced to 6 factors, reflected by 13 items from the original instrument, all with strong factor loadings. It is interesting to note that the constructs for supplier relations, demand stability, and competitive intensity were dropped from the model. We can conclude from this that, for the data of the HPM sample, the phenomena they were intended to measure are already covered by the

surviving factors. Validation of this final model can be gleaned from the overall model fit statistics, given in Table 6. Although the chi-square value of 69.926 has a significance of $p = 0.033$, its chi-square to degrees of freedom (50) ratio of 1.398 is well below the recommended threshold of 3.0 (Einwiller, 2003).

Table 6. Model Fit Statistics

<i>Model fit measure</i>	<i>Recommended value</i>	<i>CFA Model</i>
Chi-Square		69.926
Significance	$p > 0.05$	$p = 0.033$
Chi-Square/df	< 3.0	1.399
Goodness of Fit Index (GFI)	> 0.90	0.940
Adjusted Goodness of Fit Index (AGFI)	> 0.80	0.891
Comparative Fit Index (CFI)	> 0.90	0.973
Normed Fit Index (NFI)	> 0.90	0.915
Root Mean Square Residual (RMR)	< 0.05	0.044
Parsimony Goodness of Fit Index (PGFI)	> 0.50	0.516
Tucker-Lewis Index (NNFI)	> 0.90	0.958

All other fit statistics meet or exceed their respective thresholds (Gefen et al., 2003). It should be noted that the Cronbach reliability statistics for the supply chain disruption discovery and time performance constructs are somewhat low. This certainly qualifies the external validity of the paper's model and is discussed further in the concluding section. Descriptives and correlations for the model's 6 factors are given in Tables 7 and 8, below.

Table 7. CFA Constructs' Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Theory of Constraints	165	2.17	7.00	4.99	0.780
Daily Operations	165	2.50	6.70	5.21	0.829
Supplier JIT	165	2.11	6.39	4.51	0.918
Customer JIT	165	1.50	6.17	4.17	1.063
SC Disruption Discovery	165	2.67	6.40	4.87	0.684
Time Performance	165	1.75	7.00	5.00	1.005

Table 8. CFA Constructs' Pearson Correlations

	Theory of Constraints	Daily Operations	Supplier JIT	Customer JIT	SC Disruption Discovery	Time Performance
Theory of Constraints	1	0.523**	0.328**	0.357**	0.400**	0.321**
Daily Operations	0.523**	1	0.411**	0.506**	0.381**	0.300**
Supplier JIT	0.328**	0.411**	1	0.571**	0.291**	0.233**
Customer JIT	0.357**	0.506**	0.571**	1	0.401**	0.167*
SC Disruption Discovery	0.400**	0.381**	0.291**	0.401**	1	0.146
Time Performance	0.321**	0.300**	0.233**	0.167*	0.146	1

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

As might be concluded from the values in Table 8, there exists a good indication that, although the model constructs have strong unidimensionality, their measured phenomena exhibit significant relationships that can support predictive hypotheses about them. As a final step in the

analysis for this exploratory study, predictive relationships were tested with a path analysis of the measurement model evinced by CFA.

As shown in Table 9, the significant predictive relationships support the idea that an orientation to aspects of the theory of constraints in managing production leads to the perception that supply chain problems are also being discerned more successfully. Indeed, this orientation induces a more positive perception of the daily performance of manufacturing tasks, as well as of the plants' overall time performance. The existence of JIT relationships with customers is also a significant predictor of managers' positive perceptions of supply chain disruption discovery and daily task performance. Supplier JIT relationships on the other hand does not play a significant role in explaining the perceptions of time performance, daily task accomplishment, or supply chain disruption discovery in the minds of our respondents.

Table 9. Path Analysis Results

Path	R-square	beta	Standard error	Critical ratio (z)	p-value	Standardized estimate
TOC --> SC Disruption Discovery	0.384	0.378	0.103	3.676	0.000	0.480
Customer JIT --> SC Disruption Discovery		0.170	0.052	3.292	0.000	0.392
TOC --> Daily Operations	0.506	0.612	0.115	5.310	0.000	0.528
Customer JIT --> Daily Operations		0.305	0.060	5.116	0.000	0.477
TOC --> Time performance	0.261	0.671	0.202	3.326	0.000	0.511

It is noteworthy that the coefficients of determination for this model's endogenous variables are nontrivial. Indeed, fully half of the variation in perceptions of daily operations is explained by variations in managers' embrace of TOC and customer JIT. A depiction of the validated path relationships is given in Figure 1.

DISCUSSION

Several results of analysis stand out in the present study. The principle components exploratory factor analysis shows the propensity of particular groups of instrument respondents to interpret survey items in idiosyncratic ways. Although the items and their groupings have been tested and

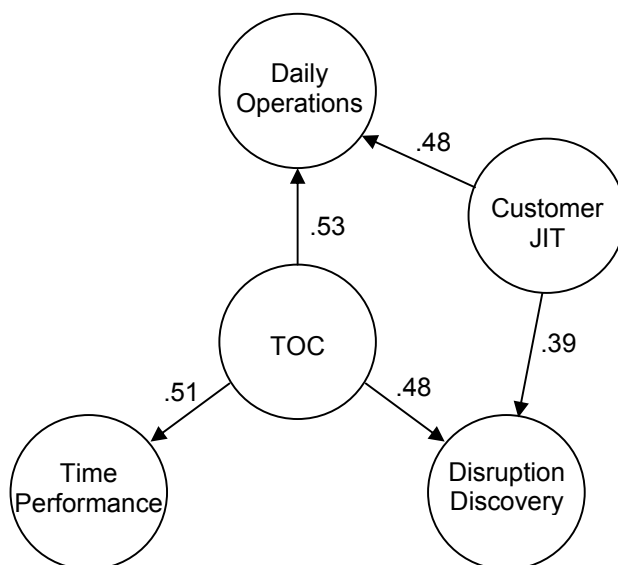


Figure 1: The Theory of Constraints and the role of Customer JIT

verified for face and content validity (Schroeder and Flynn, 2001), the contexts for their surveys can always evince different interpretations than expected. Initial factor loadings provided a guide to this in the formulation of a model to be investigated with the HPM data. Additional guidance can be gleaned from attempts to capture constructs that were not among the notions originally intended for the data collection. In this project, the concept of supply chain disruption discovery, as a separate consideration from other aspects of supply chain disruption, surfaced in the PCA stage of analysis. While reinforcing the distinction drawn by Blackhurst et al. (2005), it helped to focus the conclusions available in the analysis.

The confirmatory factor analysis is normally intended to validate a model's structural components, while removing redundancies. That stage of this analysis resulted in the conclusion that supplier relations, demand stability, and competitive intensity constructs were not contributing anything unique to the measurement model in light of the targeted factors that were also present. Although their theoretical grounding has merit in the context of this investigation's subject of study, the residual variance they share with the other factors was too high. It may be concluded that their contribution to the measurement model would have confused the conclusions that show themselves as significant. The parsimony reflected in the final CFA constructs reveals an establishment of several double-scale items in their own right, represented by the model's final constructs. It is troubling that the measures of disruption handling and time performance evince low Cronbach reliability scores. While the time performance factor may need to be supplemented with additional measures of plant performance (available in the HPM database), disruption discovery measures may well need to be targeted for specific data collection in future studies.

The path analysis conducted with the final structural model offers several insights to this exploratory effort. First, it appears that supply chain disruption discovery is indeed related to an orientation to looking out for the weak links in the chain. If the theory of constraints enjoys the attention of plant managers, this study shows that they are likely to be happier with their attempts to monitor the disruptive potentials of their supply chain networks. In fact, the theory of constraints seems to influence managers' views of the plants' overall performance, on a short-term, daily level as well as from a strategic perspective. There appears to be significant reason to consider TOC as a comprehensive approach that also has relevance to supply chain management.

An additional consideration evinced by the results of this study relates to the significance of JIT relationships in driving managers' views about short-term plant and supply chain performance issues. Customer JIT appears to play an important role here, while supplier JIT does not. Although this exploratory study is only an initial indication of such, really highlighting the need for further depth in future research efforts, a few preliminary suggestions might be gleaned from it. It could be the case that the real challenge to a manufacturing plant's attempt at keeping its products flowing is in its relationships with customers. When that can be successfully worked out to the extent that JIT would require, managers may see this as quite a positive step. It could well be that plant managers themselves see the real bottlenecks as being more related to their downstream partners, as has already been suggested in the literature (Hugos, 2003). While practitioner literature tends to place the blame for disruptions on the supplier end of the supply chain (Anonymous, 2003; Anonymous, 2005), plant managers may well view the customer end as being much more critical.

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