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Chapter 1

Analytic Hierarchy Process Applied to Supply Chain Management

Valerio Antonio Pamplona Salomon,
Claudemir Leif Tramarico and
Fernando Augusto Silva Marins

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Abstract

Resource allocation (RA) and supplier selection (SS) are two major decision problems regarding supply chain management (SCM). A supply chain manager may solve these problems by considering a single criterion, for instance, costs, customer satisfaction, or delivery time. Applying analytic hierarchy process (AHP), the supply chain manager may combine such criteria to enhance a compromised solution. This chapter presents AHP applications to solve two real SCM problems faced by Brazilian companies: one problem regarding the RA in the automotive industry and another one to SS in a chemical corporation.

Keywords: analytic hierarchy process, ranking reversal, resource allocation, supplier selection, supply chain management

1. Introduction

Supply chain is the "global network used to deliver products and services from raw materials to end customers through an engineered flow of information, physical distribution, and cash" [1]. Therefore, many decision problems make up the supply chain management (SCM). Resource allocation (RA) and supplier selection (SS) are two major decision problems regarding SCM. A supply chain manager may solve these problems by considering a single criterion, for instance, costs, customer satisfaction, or delivery time. Applying Analytic Hierarchy Process (AHP), the supply chain manager may combine such criteria to enhance a compromised solution.

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Foundations of AHP came back from the 1970s [2]. Originally, AHP consisted in hierarchy structuring, relative measurement (pairwise comparisons between criteria and between alternatives), and distributive synthesis (priorities are normalized, i.e., they sum equal to one).

One great advance in AHP practice is the “absolute measurement”, also known as “ratings” [3]. In absolute measurement, alternatives are compared with standard levels, instead of pairwise compared. Relative measurement has been most applied than ratings, even with software packages including ratings [4, 5]. Since in relative measurement alternatives must be pairwise compared, their number must be less than or equal to nine, that is, “seven, plus or minus two” [6]. In absolute measurement there is no bound for the set of alternatives. Another advantage from using ratings is the opportunity to avoid biases. With alternatives being compared with each other, two by two (relative measurement), some historical trends could be kept in mind. Comparing alternatives with a standard (absolute measurement) seems to provide a less partial or unbiased measurement.

Another advance for original AHP comes with the “ideal synthesis” [7]. With ideal synthesis, priorities are not normally distributed. That is, the sum of priority vectors components will not be equal to one. In this mode, the highest priority regarding each criterion will be equal to one. Normalizing priorities creates a dependency among priorities. However, if an old alternative is deleted or if a new one is inserted normalized priorities can lead to illegitimate changes in the rank of alternatives, known as rank reversal (RR). RR was firstly associated with AHP in preliminary studies by Professor Valerie Belton at University of Cambridge [8].

This chapter presents AHP applications to solve SCM problems. Two real cases from Brazilian companies are presented, one case regarding to RA in the automotive industry and another one to SS in a chemical corporation. In both cases, AHP was applied with absolute measurement. However, in the first case, the normal synthesis was adopted; in the second case, ideal synthesis was applied. The first conclusion from these cases is that for RA, normal synthesis maybe proper than ideal synthesis; conversely, for SS, ideal synthesis maybe more indicated.

2. Ranking reversal and synthesis mode

To illustrate the concept of RR, let us consider a decision of project selection by a company. The decision criteria are Benefits (B), Opportunities (O) and Risks (R). After pairwise comparisons, the priorities for the criteria (B, O and R) are, respectively, 73%, 19%, and 8%. Project X will be the selected one, due its highest overall priority (**Table 1**).

Project	Benefits (73%)	Opportunities (19%)	Risks (8%)	Overall
X	0.540	0.185	0.149	0.442
Y	0.348	0.659	0.691	0.434
Z	0.112	0.156	0.160	0.124

Table 1. Priorities for Projects X, Y, and Z (normal synthesis).

Let us now consider that the supplier responsible for Project Z unexpectedly discontinues its operations. So, this alternative must be deleted of the decision. Then, surprisingly, overall priority of Project Y becomes higher than Project X's (**Table 2**).

Project	Benefits (73%)	Opportunities (19%)	Risks (8%)	Overall
X	0.600	0.250	0.167	0.499
Y	0.400	0.75	0.833	0.501

Table 2. Priorities for Projects X and Y (normal synthesis).

With the same set of criteria and alternatives, but with ideal synthesis, overall priority of Project X will be higher than Project Y's, considering Project Z (**Table 3**), or not (**Table 4**).

Project	Benefits (73%)	Opportunities (19%)	Risks (8%)	Overall
X	1	0.281	0.215	0.801
Y	0.643	1	1	0.740
Z	0.207	0.237	0.232	0.215

Table 3. Priorities for Projects X, Y, and Z (ideal synthesis).

Project	Benefits (73%)	Opportunities (19%)	Risks (8%)	Overall
X	1	0.281	0.215	0.801
Y	0.643	1	1	0.740

Table 4. Priorities for Projects X and Y (ideal synthesis).

As presented in **Tables 1–4**, when one alternative is pulled out from the decision, ideal synthesis preserves ranks; conversely, normal synthesis reverses ranks. RR also may occur when new alternatives are inserted, or even when the set of criteria is changed. Matter of fact, absolute measurement and ideal synthesis always preserve ranks [9]. However, it is important to note that RR can be legitimate. That is, RR has already occurred. Two examples of real world decisions with RR are the United States Presidential Election, in 2000, and the Election of Host City of the 2016 Summer Olympics, in 2009.

The United States Presidential Election, in 2000, was quite controversial. The main contesters were Al Gore, George W. Bush, and Ralph Nader (**Table 5**).

Contester	Party	Electoral votes	Popular votes
Al Gore	Democratic	266	48.9%
George W. Bush	Republican	271	47.9%
Ralph Nader	Green	0	2.7%

Table 5. United States presidential election 2000.

Bush won with 271 electoral votes against 266 votes for Gore. It was the only fourth time, in 54 presidential elections, that the electoral vote winner failed to win also by popular vote. However, this is not an RR situation, because the set of alternatives was unchanged. An RR could have happened if Nader had quit. That is, most of Nader's popular votes could go to Gore, in a case of Nader deletion from **Table 5**. For this reason, Nader was accused of spoil the Gore presidency [10].

During the 121st International Olympic Committee Session, Rio de Janeiro was selected as the host city of the 2016 Summer Olympics. Chicago, Madrid, and Tokyo were the other applicant cities (**Table 6**). On the first round, Madrid had more votes, Rio was the second, Tokyo was the third, and Chicago, with fewer votes, was eliminated. From the second round, Rio had more votes, then, an RR occurred, and, for the first time, South America will host the Summer Olympics.

City	Round 1	Round 2	Round 3
Chicago	19.1%		
Madrid	29.8%	30.5%	32.6%
Rio de Janeiro	27.7%	48.4%	67.4%
Tokyo	23.4%	21.1%	

Table 6. Votes for host city of Summer Olympics 2016.

Depending on the type of measurement and synthesis, ranks can be preserved or reversed with AHP. Nevertheless, the main discussion is the legitimacy of RR for the decision. For instance, RR may be avoided for a president election. After all, it is not only a pair of persons (the nominee for president and the running mate) who are being elected. With the candidate, also his ideas, political orientation (conservationist or reformist, etc.), and a whole party is being selected for a four-year term. For this reason, in countries like Brazil, a two round election is adopted for presidential elections.

In another instance, for the selection of the host city for a major event, RR can be acceptable. At first, it may sound strange: X is preferred among X, Y and Z, but Y is preferred between X and Y. What happened? Who preferred Z also preferred Y than Z. In this case, RR will be legitimate. Since, AHP is a method that allows RR, its application than will be proper than other methods which not allow RR.

In Sections 3 and 4, two SCM problems are presented. For the first one, RR will not be a problem: the normal synthesis is adopted. In the second case, RR must be avoided: the ideal synthesis is adopted.

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3. AHP applied to SCM in an automobile plant

Supply chain is a network of supplier-customer companies connected by information and production flows, among other flows. For instance, a supply chain for an automobile production, beyond the car maker, or car assembler, may include auto parts manufacturers (Tiers 1 and 2 Suppliers), raw material providers, logistics providers, car dealers, and, as end customer, the car owner (**Figure 1**).

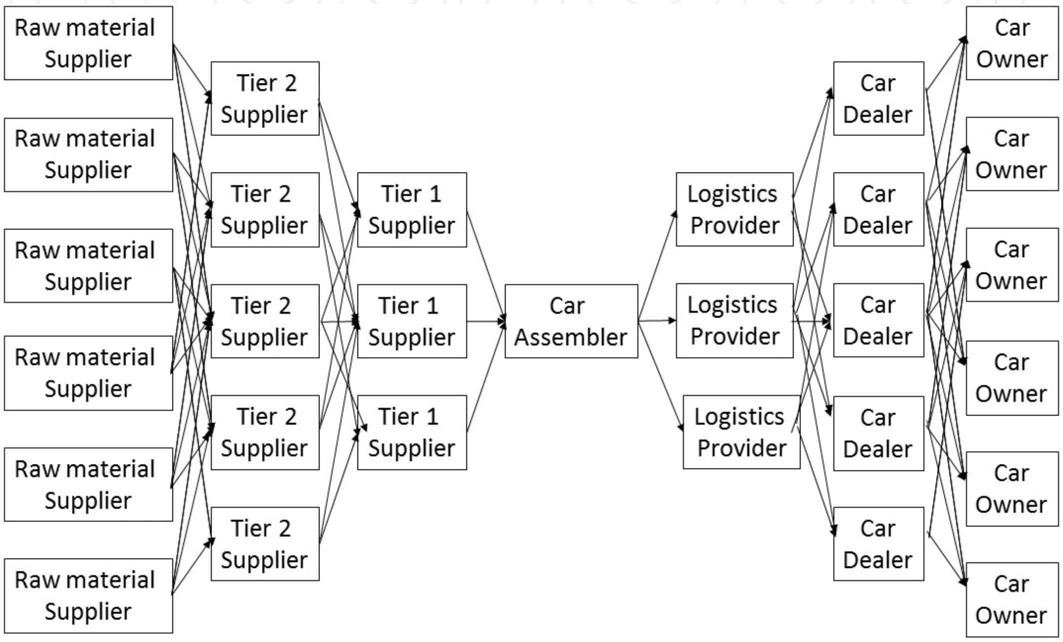

Figure 1. Automobile supply chain.

Let us consider a Brazilian manufacturer of vehicle frames, also known as chassis. This manufacturer has four plants (two in Brazil, one in Mexico, and a new one in Argentina) to closer supply its customers. These plants act as Tier 1 Suppliers for major car assemblers. In all these plants, the multiple source policy is adopted. That is, purchased items are provided eventually by more than one supplier. This policy has the main advantages of supplier competition and operational flexibility [11].

Blanking is the main process in the chassis production. Blank dies are specialized tools purchased in large lots to attend annual demands. The decision making is decentralized: buyers from each plant select suppliers for local requirements. Due to multiple supplier policy, a lot is often distributed in more than one supplier. Then, this is a resource allocation (RA) problem.

Suppliers are usually selected for a lot considering two main attributes: payment conditions and supplier loading. Usually, suppliers offering best payment conditions are selected. However, if a supplier has too many orders, then this supplier will be sidestepped. The distribution of a lot among suppliers is all done by a single buyer.

In one of the Brazilian plants, the Production Manager decides to apply the AHP, considering his team expertise to a new purchase of blank dies. The production management team, composed of three engineers, including the Production Manager, listed twelve more attributes desired for a supplier:

- Capability, that is, supplier's know-how.
- Certification of the management system, according to international standard.
- Quality, based on engineering tolerance.
- Reliability, based on expected lifetime.
- Services, post-sale technical support provided by suppliers.
- Post-sales costs, differently charged by suppliers for post-sales support.
- Flexibility, based on the supplier's skills to change product specifications or lot size in orders.
- Reaction, that is, supplier's speed to incorporate these changes.
- Sub-suppliers, that is, suppliers of the supplier.
- Price truthful (does the die worth the charged price?).

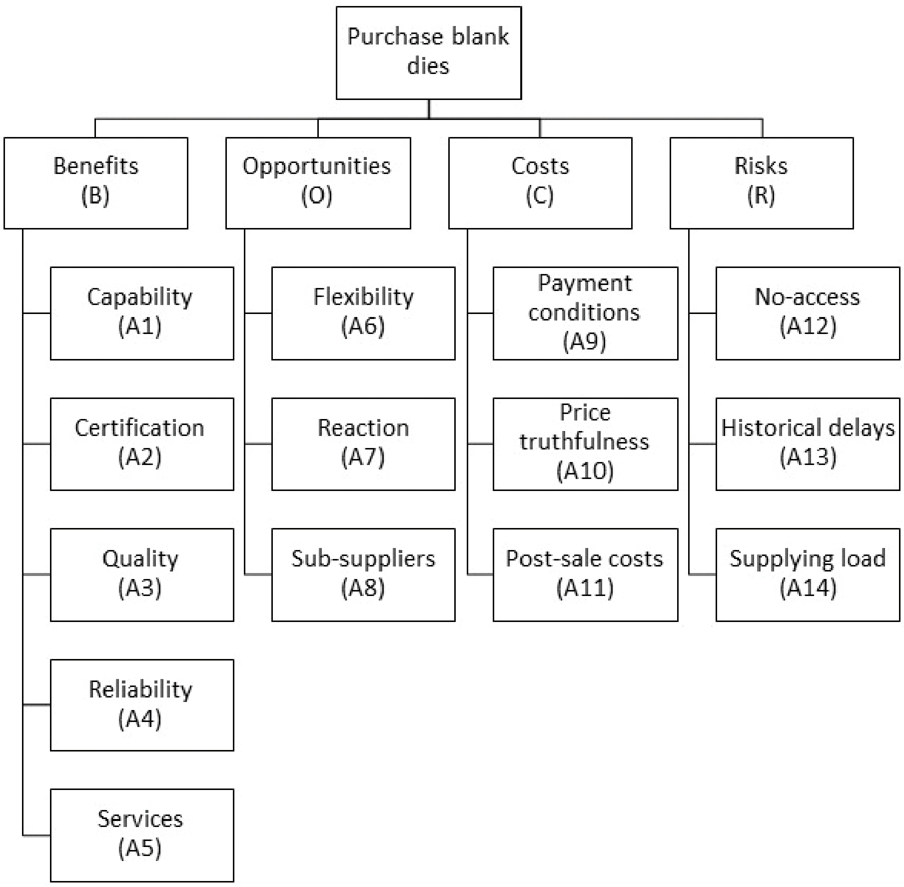

Figure 2. Hierarchy of attributes to prioritize suppliers of blank dies.

- Risk of the no-access supplier, on time, when a need for support emerges.
- Historical delays from previous deliveries.

The fourteen attributes (the new twelve plus the old two) were grouped based on the Benefits-Opportunities-Costs-Risks (BOCR) model [12], resulting in a hierarchy for the set of attributes (**Figure 2**).

The Production Manager decided that each major aspect of BOCR should equally contribute for the decision. Therefore, the overall priorities for Benefits, Opportunities, Costs, and Risks were set in 25% each. Every member of the production management team made pairwise comparisons between attributes inside the aspects (**Table 7**).

Attribute	A1	A2	A3	A4	A5
Capability (A1)	1	7	1	1	3
Certification (A2)	1/7	1	1/7	1/7	1/7
Quality (A3)	1	7	1	1	1
Reliability (A4)	1	7	1	1	3
Services (A5)	1	1/7	1	1/3	1

Table 7. Pairwise comparisons for attributes on benefits according to one member of production management team.

Comparisons made by every engineer were individually aggregated, by geometrical mean, since they are willing their preferences for the same organization [13]. This procedure results in an aggregated comparisons matrix (**Table 8**).

Attribute	A1	A2	A3	A4	A5	Priority
Capability (A1)	1	$(392)^{1/3}$	$(6)^{1/3}$	$(1/6)^{1/3}$	$(6)^{1/3}$	26%
Certification (A2)	$(1/392)^{1/3}$	1	$(1/280)^{1/3}$	$(1/567)^{1/3}$	$(315)^{1/3}$	3%
Quality (A3)	$(1/6)^{1/3}$	$(280)^{1/3}$	1	$(1/15)^{1/3}$	$(6/5)^{1/3}$	17%
Reliability (A4)	$(6)^{1/3}$	$(567)^{1/3}$	$(15)^{1/3}$	1	$(8/3)^{1/3}$	35%
Services (A5)	$(1/6)^{1/3}$	$(315)^{1/3}$	$(5/6)^{1/3}$	$(3/8)^{1/3}$	1	19%

Table 8. Pairwise comparisons for attributes on benefits aggregated to all member of production management team.

The local priorities for all attributes can be obtained normalizing the right eigenvector for the aggregated comparison matrices. The overall priorities for the attributes are obtained weighting local priorities by 25% (**Table 9**).

Attribute	Overall priority
Capability (A1)	7%
Certification (A2)	1%
Quality (A3)	4%
Reliability (A4)	8%
Services (A5)	5%
Flexibility (A6)	6%
Reaction (A7)	13%
Sub-suppliers (A8)	6%
Payment conditions (A9)	17%
Price truthfulness (A10)	4%
Post-sale costs (A11)	4%
No-access (A12)	2%
Historical delays (A13)	5%
Supplying load (A14)	18%

Table 9. Overall priorities of attributes for suppliers of blank dies.

The production management team prioritized six potential suppliers with ratings, that is, relative measurement, by consensus. They prioritized the suppliers rating them in a 0–1 linear scale (**Table 10**). For Certification (A2), the priority value was binary: 1, when the supplier had a certified management system, or 0, otherwise.

Supplier	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
S1	0.8	1	0.7	0.8	0.8	0.8	0.9	0.9	0.6	0.6	0.7	0.8	0.9	0.9
S2	0.7	0	0.8	0.7	0.8	0.9	0.7	0.8	0.7	0.8	0.8	0.8	0.7	0.8
S3	1	1	0.9	0.9	0.9	0.7	1	1	0.5	0.5	0.7	0.7	0.7	0.9
S4	0.8	0	0.9	0.9	0.8	0.9	0.8	0.8	0.8	0.9	0.8	0.9	0.9	0.8
S5	0.7	1	0.8	0.85	0.9	0.8	0.6	0.8	0.3	0.3	0.8	0.9	0.8	0.7
S6	0.5	0	0.6	0.6	0.6	0.5	0.2	0.6	1	1	0.5	0.2	0.5	0.5

Table 10. Rated suppliers of blank dies.

S5 was the most expensive supplier (A9 = 0.3) and S6 was the cheapest one (A9 = 1). However, S6 will be not be selected, since it was relatively overloaded (A14 = 0.5). Usually, a buyer makes this decision. Sometimes, buyers make unpredictable decisions for production management.

Then, Production Manager decides to go on with AHP application. Next step is normalizing priorities for each attribute. Then, normalized priorities need to be weighted by criteria priorities (**Table 9**). This way, a decision matrix brings local priorities for each aspect (BOCR) and overall priorities (**Table 11**).

Supplier	Benefits (25%)	Opportunities (25%)	Costs (25%)	Risks (25%)	Overall
S1	17.4%	19.7%	15.4%	19.6%	18.0%
S2	15.1%	17.3%	18.3%	17.1%	17.0%
S3	20.4%	20.9%	13.3%	18.5%	18.3%
S4	17.4%	18.5%	20.4%	18.2%	18.6%
S5	17.9%	15.5%	9.4%	16.2%	14.7%
S6	11.7%	8.0%	23.2%	10.4%	13.3%

Table 11. Local and overall priorities for suppliers of blank dies.

Production Manager decided to delete Suppliers 5 and 6 for the next supplying of blank dies. Then, the lot will be equally divided in four suppliers (S1–S4). The overall priorities for suppliers will change from (18.0%, 17.0%, 18.3%, 18.6%, 14.7%, 13.3%) to (25%, 25%, 25%, 25%). This is not a case of ranking reversal. If S5 and S6 were deleted in **Tables 10** and **11**, overall priorities will be (25.0%, 23.7%, 25.3%, 26.0%). Therefore, AHP application supported the Production Manager decision.

Production Manager, finally, communicates the decision to procurement management. The new role for buyers will be only to contact suppliers and purchase the blank dies. After all, production will be the user of the blank dies in their processes, not the buyers. No contest emerged, and the company was confident that select suppliers not only based in costs and risks, but also considering benefits and opportunities would be a better decision.

4. AHP applied to SCM by a chemical corporation

Outsourcing is an increased business practice. Instead of directly providing to customers, suppliers may contract third-party companies to perform non-core activities. Functions often outsourced include accounting, human resources, and marketing [14]. Logistics of finish goods to resellers is 100% outsourced by a chemical corporation in Brazil. That is, Third-Party Logistics (3PL) providers transport all items produced in the Brazilian plants to distribution centers. Land transport is the dominant mode of transport, and there are three 3PL providers. When a plant requires a new transportation, from the corporate office, located in Sao Paulo City, one of four buyers selects a 3PL provider. There is no structured method to select 3PL providers. Then, the Supply Chain Manager decided to apply AHP to select a 3PL for a new transportation order.

Desired attributes for a 3PL provider include [15, 16]:

- Costs.
- Financial performance.
- Geographical location.
- Information technology.
- Operations performance.
- Quality.
- Responsiveness.
- Risks.
- Workforce.

The SCM team grouped 27 attributes, relevant for 3PL of the chemical corporation, in a BOCR model (**Figure 3**).The fourteen attributes regarding to Benefits were grouped as structural benefits or technological benefits.

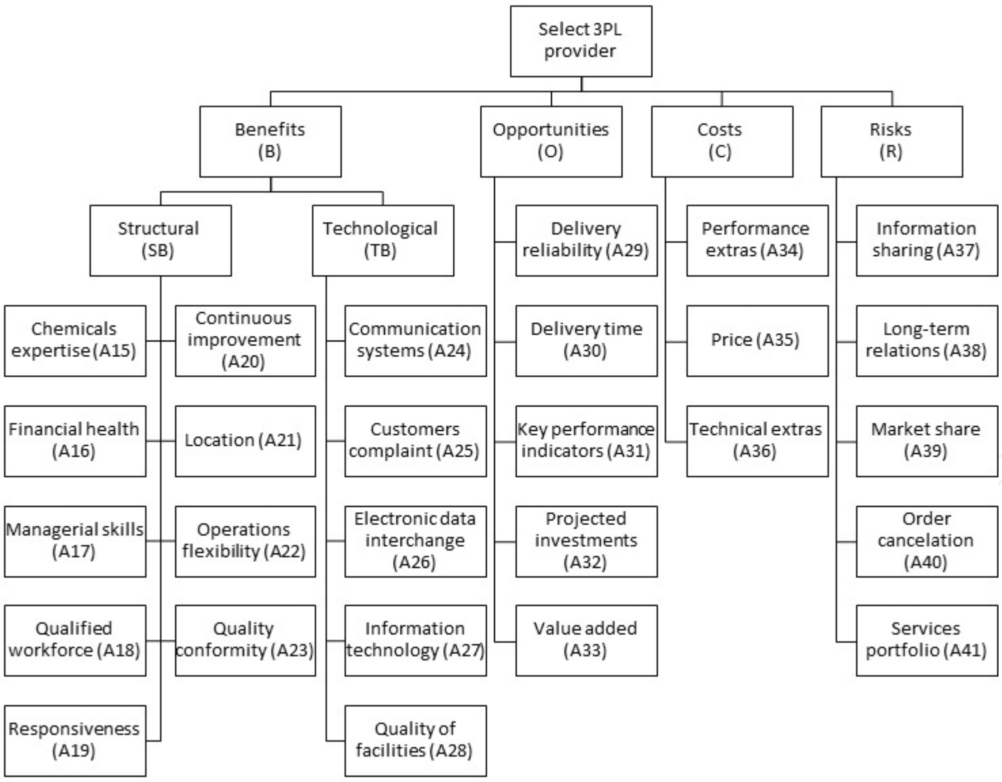

Figure 3. Hierarchy of attributes for third-party logistics provider.

As in the previous case of blank dies supplier selection, the chemical corporation's SCM team decided that each major aspect of BOCR should equally contribute for the decision. Then, the overall priorities for Benefits, Opportunities, Costs, and Risks are also 25% each. Every member of SCM, including the Supply Chain Manager, compared the attributes inside the aspects. They input their judgments in an AHP web-based software. This software enables comparison values with two decimal points, as 2.33 (**Table 12**).

Costs	A34	A35	A36
Performance extras (A34)	1	2.33	0.70
Price (A35)	1/2.33	1	0.40
Technical extras (A36)	1/0.70	1/0.40	1

Table 12. Pairwise comparisons for attributes on benefits according to one member of supply chain management team.

Comparisons made by every SCM member were individually aggregated, by geometrical mean, resulting in aggregated comparison matrices, which resulted in the local priorities for the attributes (**Table 13**).

Costs	A34	A35	A36	Local priority
Performance extras (A34)	1	$(0.122)^{1/5}$	$(0.233)^{1/5}$	25.9%
Price (A35)	$(1/0.122)^{1/5}$	1	$(2.238)^{1/5}$	39.8%
Technical extras (A36)	$(1/0.233)^{1/5}$	$(1/2.238)^{1/5}$	1	34.3%

Table 13. Pairwise comparisons for attributes on costs aggregated to all member of supply chain management team.

The local priorities for all attributes can be obtained normalizing the right eigenvector for the aggregated comparisons matrices. The overall priorities for the attributes A29–A41 are obtained weighting local priorities by 25%; for A15–A28, local priorities must be weighted by 12.5%, since local priorities for structural benefits and technological benefits are 50% each (**Table 14**).

Attribute	Overall priority
Chemicals expertise (A15)	1.0%
Financial health (A16)	1.9%
Managerial skills (A17)	1.6%
Qualified workforce (A18)	1.4%
Responsiveness (A19)	1.7%
Continuous improvement (A20)	1.7%
Location (A21)	1.2%
Operations flexibility (A22)	1.2%

Attribute	Overall priority
Quality conformity (A23)	0.8%
Communication systems (A24)	2.7%
Customers complaint (A25)	2.7%
Electronic data interchange (A26)	2.1%
Information technology (A27)	2.1%
Quality of facilities (A28)	2.9%
Delivery reliability (A29)	5.8%
Delivery time (A30)	5.4%
Key performance indicators (A31)	3.6%
Projected investments (A32)	3.9%
Value added (A33)	6.3%
Performance extras (A34)	6.5%
Price (A35)	9.9%
Technical extras (A36)	8.6%
Information sharing (A37)	4.3%
Long-term relations (A38)	4.9%
Market share (A39)	5.1%
Order cancellation (A40)	6.3%
Services portfolio (A41)	4.4%

Table 14. Overall priorities of attributes for 3PL providers.

In this case, AHP must be applied with absolute measurement and ideal synthesis, since RR is not desired. The rating of 3PL providers will be based on a five-level scale from Poor to Excellent performance (**Table 15**).

Level	L1	L2	L3	L4	L5	L6	Priority
Excellent (L1)	1	2	3	5	7	9	1
Between excellent and very good (L2)	1/2	1	3	4	7	8	0.75
Very good (L3)	1/3	1/3	1	5	6	8	0.49
Between very good and good (L4)	1/5	1/4	1/5	1	6	8	0.25
Good (L5)	1/7	1/7	1/6	1/6	1	3	0.10
Poor (L6)	1/9	1/8	1/8	1/8	1/3	1	0.06

Table 15. Levels of performance [16].

By consensus, the SCM team rated three 3PL providers, for every attribute (**Table 16**).

3PL provider	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28
S7	L1	L2	L4	L2	L1	L3	L2	L2	L1	L4	L5	L2	L2	L4
S8	L1	L4	L1	L3	L3	L2	L3	L3	L2	L3	L3	L3	L3	L5
S9	L1	L2	L2	L3	L4	L4	L1	L4	L3	L2	L3	L3	L1	L6

Table 16. Rated 3PL providers according to benefits.

Local priorities regarding every criterion are obtained with the priorities of levels L1–L6. Overall priorities for 3PL providers (**Table 17**) are obtained weighting local priorities by the priorities of attributes.

3PL provider	Benefits	Opportunities	Costs	Risks	Overall
S7	0.55	0.75	0.25	0.54	0.52
S8	0.51	0.49	0.56	0.7	0.57
S9	0.55	0.42	0.53	0.65	0.54

Table 17. Local and overall priorities for 3PL provider.

Overall priorities for 3PL providers indicate medium performances for the suppliers. SP8, SP9 and SP7 are almost tied with respective overall priorities equal to 0.57, 0.54 and 0.52. However, these priorities were obtained with balanced priorities for the major aspects of BOCR model.

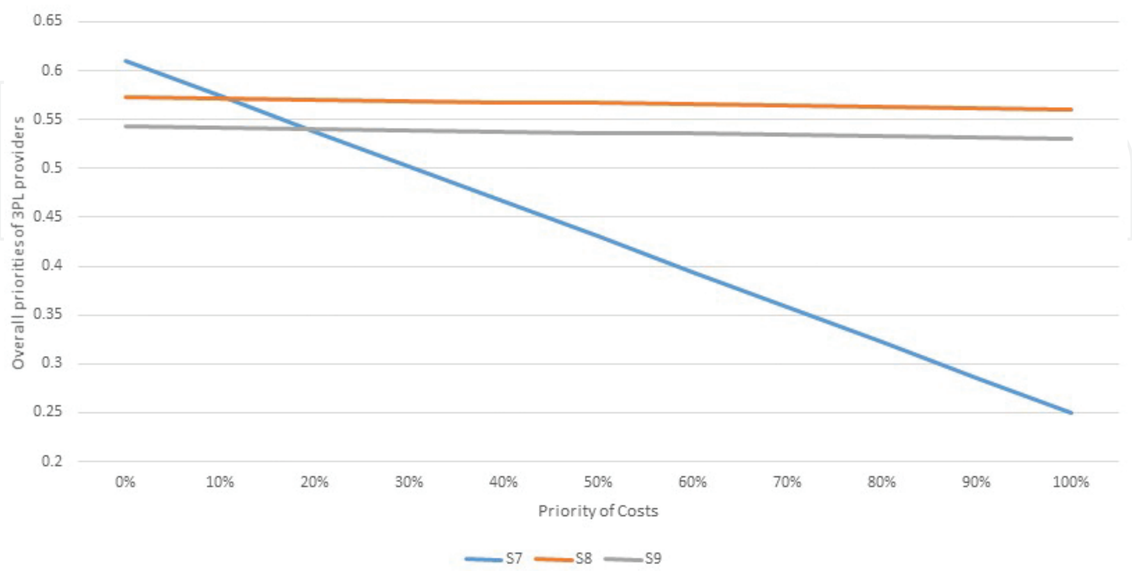

Figure 4. Sensitivity analysis of 3PL providers' overall priorities to priority of costs.

The current Brazilian scenario, with economic recession, suggests unbalances favoring Costs and Risks. Then, after sensitivity analysis (**Figure 4**), SP8, SP9 and SP7 were prioritized in this order. That is, when available SP8 will be chosen as 3PL provider; SP7 will provide 3PL only when both SP8 and SP9 were not available.

The SCM team validated the results. The experts considered the AHP based model as applicable in practice. Besides the results are considered adequate, the steps of AHP were perceived as a better practice for supplier selection to logistics.

5. Conclusions

This chapter presents two applications of AHP to SCM. In both applications, absolute measurement was adopted instead of the original relative measurement. That is, in both applications the set of criteria was larger than usual AHP applications. With absolute measurement pairwise comparisons between suppliers are not necessary. This way, the effort for the AHP application is reduced. However, this is not the main reason for absolute measurement, in both cases. In the case of RA by an automobile plant, there was feeling that the decision must be impartial. That is, pairwise comparing Supplier S1 with S2 may invoke past deficiencies already overcome.

Another reason for absolute measurement, only for the SS by a chemical corporation, is the avoiding of RR. That is, for a problem of SS, RR seemed not justifiable. If Supplier S8 is preferred than S7 and S9, it must be preferred without S7 or S9 in the decision, and even if other Suppliers S10, S11, S12, …, all worst then S7 were inserted in the decision. Concluding: there is no space for RR in SS. For that reason, AHP must be applied to SS with absolute measurement and ideal synthesis.

On the other hand, adding new suppliers in an RA problem may change previous priorities of older suppliers. This way, RR can be legitimate for this problem. Then normal synthesis, and also, relative measurement, seems to be proper procedures for AHP application to RA.

It is important to state that this chapter presents some highlights based on only two cases. Obviously, more examples and real cases must be studied to generalize our conclusions. Perhaps the main contribution of this work is presenting that there are different ways to solve a problem. The way a problem is solved defines a decision, which may be irreversible, as the selection of a supplier to a specific order.

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Author details

Valerio Antonio Pamplona Salomon*, Claudemir Leif Tramarico and
Fernando Augusto Silva Marins

*Address all correspondence to: salomon@feg.unesp.br

Sao Paulo State University, Guaratingueta, Brazil

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