Ranking of factors that underlay the drivers of Sustainable Manufacturing based on their variation in a sample of UK manufacturing plants

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Please cite this article as:

Fargani, H., Cheung, W.M., Hasan, R., (2017), "Ranking of factors that underlay the drivers of Sustainable Manufacturing based on their variation in a sample of UK manufacturing plants", International Journal of Manufacturing Technology and Management, (in press).

Abstract:

The trend towards environmental sustainability has encouraged research to explore this new area in manufacturing. Part of the research effort is directed at identifying the drivers of this new development to understand how it is impacting traditional manufacturing. Government regulations, customer demand, and cost savings are amongst many drivers that have been identified. Research so far, however, represents merely the tip of the iceberg of a very complex phenomenon. A deeper understanding of the factors affecting these drivers is lacking. This study, therefore, aims to identify factors that support some sustainability drivers. This study has identified four key drivers and the factors that underlie them. For example, customer demand is a driver that was found to be influenced by underling factors such as the bargaining power of customers and the importance of environmentally-friendly products to win orders. Ten underlying factors are described and then analysed by conducting statistical tests that show their variation in a sample of manufacturing companies. Based on the principle that the control of variation could lead to potential improvements, these factors are ranked according to their variation in the sample. The novelty of this study is its attempt to provide deeper knowledge of what influence the strength of sustainability drivers by shedding light on the factors that underlie them. The approach used to rank the factors based on their variation is also unique and has the potential to be widely used to identify opportunities for improvements in other areas.

Key words: Sustainable Manufacturing, Statistical analysis, variation control, Environmental Management, Sustainability Drivers, Operations Management.

Abbreviations table

Abbr.	Full Phrase
SM	Sustainable Manufacturing
GSC	Green Supply Chain
GSCM	Green Supply Chain Management
CSR	Corporate Social Responsibility
EMS	Environmental Management System
PCA	Principle Component Analysis

1. Introduction

Efforts to reduce the impact of human activity on the environment have been increasing in recent decades as an awareness of environmental issues has spread beyond the scientific community. Politicians now regard environmental sustainability as a priority and use government power to impose it. The manufacturing industry is particularly responsible. As the sector consuming the most energy and because of its waste and emissions, manufacturing industry is particularly responsible [1, 2]. A lot of research has been conducted at a technical level on the energy consumption of manufacturing operations [3-5] and also on the environmental impact of waste and emissions [6]. Other research addresses sustainability at system level so as to explore the requirements for manufacturers to become sustainable. Kashmanian, et al. [7] identified these requirements and classified them into stages through which a company progresses to transform itself into an environmentally sustainable company. During this transformation, some drivers play an important role in enabling manufacturers to integrate environmentally friendly practices into their management system in order to achieve a state of Sustainable Manufacturing (SM).

To fully understand the importance and effect of SM drivers, the factors that underlie these drivers need to be brought to light and investigated. This study, therefore, reviews the literature to identify factors that support the drivers of sustainable manufacturing, and then uses data collected from 36 manufacturing companies based in the UK to analyse these factors and assess their relevant importance.

2. Literature Review

Research on the drivers of SM has been very active in the last two decades. The most influential driver of SM prior to and during the 1990s was governmental regulations [8]. However, as companies started to look beyond legal requirements, for various reasons such as pressure by non-government bodies, cost savings, PR and customer demand, the strategies of these companies shifted from being merely in compliance to going beyond compliance [7]. As a result, research in this area has grown rapidly to cover the influence of various drivers that facilitate the pursuit of better environmental performance.

A study by Mittal and Sangwan [9] into the drivers of SM supports the view that their influence is changing. They developed a fuzzy TOPSIS method to rank 13 drivers and concluded that four drivers are the most important for adopting SM. These four drivers are; competitiveness between companies, incentives given by governments, organisational resources, and technology. Table 1 shows the drivers in their ranking order and some examples. However, the influence of the drivers seems to depend on matters such as the type of sector involved, geographical region and the maturity of the market. For example, Zhu, et al. [10] found that the most important driver for the Chinese automotive industry is regulatory requirements, which is different from the findings of Mittal and Sangwan [9]. The importance of drivers in different industrial sectors has been highlighted by Kumar, et al. [11], who found that sustainability dynamics depend on the size of industrial sector, type of product and the presence of specialist companies that can provide green technologies.

[Please insert Table 1 here]

The success of SM depends on the above-mentioned drivers, and these drivers in turn depend on factors that determine their strength. For example, the driver of supply chain pressure depends on factors such as the bargaining power of suppliers, and the level of supply chain integration. A review of the literature on SM did not produce a single study relating these factors to the drivers. Thus, survey data was used to identify SM drivers and their underlying factors. The authors acknowledge that the data available from the survey is limited and allows only for the study of a few factors that support some drivers. However, the main objective at this stage is to raise awearness of the importance of researching the factors rather than the typical focus on the drivers themselves. The following is a review of the drivers included in this study and their underlying factors.

2.1. Supply Chain Pressure

In the area of green supply chain management (GSCM), the drivers of change are similar to those found in single manufacturing companies. Walker, et al. [12] found that studies of GSCs tend to focus on drivers rather than barriers due to the desire to focus on positive aspects of GSC. They also found that large organisations in the private and public sectors are likely to hold the power to influence suppliers in responding to an environmental agenda. This makes the size of a company a very important underlying factor for the driver supply chain pressure and, indeed, an important underlying factor of other drivers.

Another important factor is the level of supply chain integration. Growing evidence suggests that the higher the integration with suppliers and customers, the greater the environmental benefits [13]. In addition, the bargaining power of suppliers is very important in increasing or decreasing the pressure on companies to adopt SM. In a study on greening the supply chain, Liang and Jing [14] concluded that joint efforts between companies in innovation provide the best outcomes for emissions reduction.

2.2. Market Pressure

Zhu, et al. [10] used the term (market pressure) in their research to cover market-related drivers such as customer demand, peer pressure and public image. The market associated with environmentally-friendly products has been researched for over a quarter of a century. Welford and Gouldson [13] reported that in the year 1990 the size of the market for “environmental improvements” was estimated at $200 billion worldwide and expected to grow rapidly. In 2011, in the UK alone, the green goods and services sector was worth £122 billion [15].

The findings of a study of Global Corporate Social Responsibility (CSR) [16] illustrate that a rapid shift is underway in global markets towards environmental products and activities. The study covered more than 10,000 citizens from 10 of the largest countries by GDP. An important finding of the study is that customer awareness of social and environmental issues is a significant cause of this change. An important accelerator of this awareness is social media, where bad or good news about a company could change its reputation and consequently its market share. On a global level, the CSR study found that more people tend to shop for products and services that provide social and environmental benefits. In addition, consumers use their purchasing power to protest against irresponsible products. Nine out of ten global participants would boycott a company if they learned of its irresponsible practices. In fact, more than half (55%) had done so in the previous 12 months according to the same report.

The factors available in studying the market pressure driver are: market competition and market concentration. These two factors differ in nature, as in some markets competition is fierce even if the number of competing companies is small. Markets in new technologies are examples of this type. Whereas in other markets, a large number of companies may work in a low competition environment.

The bargaining power of customers and the importance of environmentally-friendly products to win orders are also factors that affect the market pressure driver. Customers such as large companies and state institutions in countries that tackle climate change demand for products and services with low ecological impact [1].

2.3. Competitiveness

Making the most out of resources is an important approach to win in competition. Manufacturing companies learned a key lesson from the Japanese car maker Toyota as the company practised its Toyota Production System, also known as Lean Manufacturing [17], to achieve better process performance, higher product quality and higher efficiency, which are the underlying factors that support the driver competitiveness. Moreover, Lean Manufacturing provides a strong base for SM as it reduces the consumption of resources and wastes [18]. Six Sigma is another important management system that has been adopted very successfully in manufacturing industry [19]. Similar to Lean Manufacturing, Six Sigma improves quality, delivery time and flexibility to promote competitiveness [20]. Lean and Six Sigma, therefore, are considered in this study as factors supporting the competitiveness driver.

3. Research Methodology

3.1 Defining the population and selecting the sample

The focus of this study is manufacturing industry, and therefore, the target population would naturally be manufacturing companies. This target was narrowed down to include UK manufacturers who the authors could easily reach, since the research project was limited in terms of time and budget. The questionnaire was targeted at only one individual in a company who holds the position of production, quality or general manager. Although this affected the design of the questions in terms of depth, and also increased the possibility of "subjective bias due to an individual's unique perspective and limited access to information" [21], this was unavoidable because the response rate would significantly drop if multiple individuals in the same company were targeted. Nevertheless, this limitation helped in assessing the state of communication between departments based on the knowledge of the respondent about other departments. In other words, if the respondent was a production manager who skipped general questions about other departments, such as questions about market conditions or whether or not the company had conducted life-cycle assessment, this would indicate a possible problem with internal communication.

A sample from the population was selected randomly in order to ensure better representation of the whole population. Random sampling also ensures that the sample has the same composition and characteristics as the population it is drawn from [22].

The survey was targeted at production, quality or general managers at plant level. Although those at corporate level may have a more holistic view of the firm's plants and may provide more information, plant level staff may also be appropriate for operations management studies concerning strategy [23]. For example, the Minnesota-Iowa State research on World Class Manufacturing (WCM) used the plant as the level of analysis, even though WCM is a strategic approach, because many WCM initiatives involving measurable improvements occur at plant level [23].

To identify target companies, general information about manufacturing companies published by trade associations such as the British Engineering Manufacturers' Association (BEMA), Federation of Environmental Trade Associations (FETA), Engineering Employers Federation (EEF), and others, was used to produce a list of targets. Non-manufacturing companies were systematically excluded from the search results. To find specific information about the production/quality/operations managers in target companies, a search was conducted by making phone calls and sending emails to readily available general company email addresses, such as sales@, enquiries@ and info@. Sending emails to these addresses produced no feedback, whereas phone calls to enquire about contact information for managers usually faced the obstacle of company policy not to transfer calls unless the manager's name is known to the caller. To overcome this obstacle, LinkedIn, which is a business and employment-oriented social networking service, was used to obtain the names of managers in the targeted companies. The names obtained allowed for calls to be transferred to managers who were then invited to take part in the questionnaire survey. LinkedIn was also used to contact potential respondents directly by making contact requests; none of which, however, was accepted by the targeted participants.

3.2 Questionnaire Design

The empirical data used in this study consists of questionnaire responses from staff of manufacturing businesses based in the UK. The primary goal of the questionnaire was to help develop a conceptual framework to improve the sustainability of manufacturing businesses [24, 25]. The questionnaire covered four sections: (i) market conditions, (ii) development investments, (iii) operations management and (iv) environmental practices. Questions for the first and third sections were developed based on items used in the International Manufacturing Strategy Survey [26] using a five-point Likert-scale. The second section consisted of a question about the size of annual investments in developing: (a) product-related R&D, (b) processes and equipment, (c) staff training and education and (d) environmental programmes. The fourth section was made up of questions about environmental practices such as the availability of an Environmental Management System (EMS). The items in this section were all developed by the authors due to the lack of relevant constructs in the literature.

Previous studies that have looked into ranking the drivers of SM have mostly relied on direct questions to participants to collect data and prioritise the drivers (see for example [9, 10]). In this study, however, participants were asked about factors without directly mentioning the drivers. This method provides two benefits, as follows.

Firstly, it reduces bias since companies tend to overstate their efforts and interest in sustainability. Walker, et al. [12] point out that companies often do not change their practice but merely advertise that they do. Raiborn, et al. [27] also indicated that management exaggerate when reporting their environmental performance. To avoid this, no direct questions concerning the drivers are included in the questionnaire, as the outcome might not be accurate.

Secondly, multi-item constructs increase content validity and enhance confidence in the results. Malhotra and Grover [28] stress that single-item questions have "considerable measurement error" and thus they encourage developing multi-item constructs using the framework shown in Figure 1. For example, if a respondent was asked, for example, to evaluate the driver supply chain pressure, the answer would be not as accurate as asking multiple and more specific questions about the supply chain, such as questions concerning supply chain integration, the importance of environmental products to suppliers, and the bargaining power of suppliers.

[Please insert Figure 1 here]

3.2. Data Collection

While the questions addressed issues relevant to the marketing, finance and operations departments, the questionnaire was targeted at one individual, who might be a production, quality or general manager. Although this may affect the depth of the questions and increase the possibility of "subjective bias due to an individual's unique perspective and limited access to information" [21], it was unavoidable as the response rate would significantly drop if multiple sources in the same company were targeted. Nevertheless, this limitation helped in assessing the state of communication between departments based on the knowledge of one manager about other departments [25]. In other words, if the respondent is a production manager who skipped general questions about other departments, such as questions about the market conditions or whether or not the company had conducted Life Cycle Assessment studies, this might indicate an internal communication problem.

The survey was administered using Survey Monkey and supported by telephone invitations whenever possible. Fellow academics were also requested to invite their contacts in industry, as endorsement can improves response rates significantly [29]. Managers from a total of 36 companies from 8 different sectors responded to the questionnaire.

4. Results and Discussion

4.1 Identifying the Factors

The data available from the survey is limited and allows ,only for the study of ten factors that support some drivers. Studying the effect of drivers was not the main focus of the survey design and thus it included factors that relate directly to a framework proposed in a research project [24, 25]. Drivers such as regulations and their supporting factors were beyond the scope of the current study. The drivers and supporting factors that were analysed are shown in Table 2. Lean manufacturing and Six Sigma can be considered as underlying factors that support more than one driver, such as competitiveness and cost savings. Similarly, company size plays an important role in supporting many drivers. The success of SM depends on the above drivers, and these drivers, in turn, depend on factors that determine their strength. For example, the supply chain pressure driver depends on factors such as the level of supply chain integration, where the stronger this factor is, the stronger the driver becomes.

[Please insert Table 2 here]

4.2. Ranking the Factors Based on Their Variation

This paper assumes that a group of manufacturers in the same business environment, such as manufacturers in a certain business sector, should have similar state-of-the-art management systems, similar levels of supply chain integration, and similar customer expectations in issues such the environment. This assumption reflects the ultimate aim of benchmarking for companies as "*benchmarking is an approach used for evaluating and improving company performances, by* *comparing them with the best performing companies*" [30] This paper aims to show the areas, represented by factors, where benchmarking is most urgently required in the context of SM.

In statistical process control, variation signals an opportunity for improvement [31]. The priority of actions taken to achieve this improvement starts with problems that cause large variations and moves on to problems that cause less variation. If the same principle is applied to the variation within a sample population, opportunities for improvement will arise from reducing the causes of variation. For example, if companies differ significantly in using a certain management technique, such as varying in their level of practice or where some use it and some do not, this management technique should be investigated to find out why it is not a standard technique since there could be an opportunity for improvement available. This suggests that variation is a window to opportunity, and that the two terms are interchangeable. Finding the cause of inconstancy amongst companies in the same industry, the manufacturing industry in this case, in areas such as operations management and environmental management will reveal improvement opportunities.

The aim of this section, however, is not to explore opportunities, but rather put a set of opportunities (variables) to the test to find out how much variation exists in order to produce a prioritization list where it is more important to investigate larger variations. In this case, the ten factors identified in the previous section will be tested to produce a ranking of the factors in terms of the opportunity they offer to improve SM.

To prioritize the factors that we categorized as supporters of SM drivers, a Principal Component Analysis (PCA) test was conducted. PCA is a technique used to identify groups or clusters of variables [32]. In a large set of data, PCA is typically used for data reduction by means of finding groups of variables that explain most of the variation in a sample population. The test splits the variables into a number of components (groups) based on the interrelationships between these variables.

The test will also determine the importance of each component/group based on the percentage of variance it explains. The loading of variables on each of the groups/components will determine the ranking of the factors under investigation. A simple example would be a study of year 1 pupils at a local school. Much information can be gathered including dress style, height, age, family size, distance to home, and much more. A long list of the different characteristics of each pupil can be created. However, many of them will measure similar features, and so will be redundant. Therefore, PCA finds the best characteristics to summarize the list of variables as thoroughly as possible, grouping them as components and showing each component's share in the total variation.

However, the goal of using PCA here is not to summarize a large number of variables. The test will be used to rank the factors under study based on the total variance they represent. A typical application of PCA requires a large sample size to improve the accuracy of the results. However, the technique is applied in this study only to illustrate a logical approach to identifying variation and provide a ranking for a set of problems; the accuracy of the outcome is not a major concern at this stage. The analysis was performed using the statistical software SPSS. A Kaiser-Meyer-Olkin (KMO) test shows if the data allows the identification of patterns of correlations between variables. A KMO value of zero indicates diffusion in the pattern of correlations [32] and hence PCA is not suitable, whereas a value close to 1 indicates that the correlations are clustered in a way that allows components to be identified. The results of the KMO test confirm that our sample is adequate for conducting PCA as the cut-off value of 0.5 KMO is exceeded with a significance of less than 0.05 (Sig.=0.003). The PCA

RESULTS revealed the presence of four groups with eigenvalues exceeding 1. These groups are arranged according to the percentage of variance they explain as shown in Table 3. This means that, in our sample population, the variables under study have been grouped into components, four of which are statistically significant with eigenvalues greater than 1. Table 4 shows the loading strength of each of the variables on the different components/groups.

[Please insert Table 3 here]

[Please insert Table 4 here]

Based on the information in Table 3, a ranking order of the components is obtained. The next step is to determine which variables each component is made of. To improve the interpretation of the results, rotation is used. Rotation maximizes the loading of each variable on one of the principal components while minimizing the loading on all other components, which makes the observation of variables relating to each component clearer [32]. Varimax with Kaiser Normalization is the default rotation method in SPSS. According to their component contributions and their loadings on these components, the variables, are presented in Table 3 where each component is assessed in terms of correlations with the variables it contains as shown in Table 3. Therefore, the factors in Table 3 are ranked according to their importance.

Opportunities for improvements lie where there is a significant difference between companies in the sample population. In Table 2, the significant differences are represented by four components, or groups of variables, which account for 79.79% of the total variance.

The results show that the first component consists largely of items that relate to process management and managing the supply chain. This suggests that companies vary significantly in their application/performance in these areas. The application of Six Sigma is ranked first, meaning that there is no consistency in the use of Six Sigma amongst companies. Given that variation signals an opportunity, an investigation of the reasons why Six Sigma is not a standard application in the quest for SM should be the starting point for improvements. Sequentially, the investigation then moves to the other factors to find more opportunities.

In studies that rank SM drivers, participants are asked to rank the drivers as a single variable, which results in an incomplete understanding of SM. It is observed from the results of this study that fragmenting the SM drivers into their underlying factors provides a better picture of the latter's significance. Whereas in typical SM studies, the importance of individual factors is overlooked.

Such analyses provide the level of details needed for guiding research projects to give focus and direction to the efforts to improve SM or any other management field by means of providing a priority plan. It can be also used by government departments that work on promoting SM within a region or industry. According to the current findings, for example, governments should facilitate access to training for Six Sigma and Lean as a first step in promoting sustainability. Large companies with multiple factories might also benefit from knowing the source of variations, for example in the level of applying management techniques, within these factories and to work on reducing these variations to achieve standardization. The study and ranking of the factors rather than the drivers can be also useful when an individual company decides to embark on sustainability programmes. The information obtained will assist in conducting a SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis.

5. Conclusion

Much attention has focused to the SM drivers in terms of their importance in supporting sustainable manufacturing. However, a more detailed understanding of how different factors affect the strength of these drivers is lacking. This understanding will allow manufacturers to focus on specific factors rather than general drivers. In this study, data from a survey of manufacturing companies was used to analyse ten factors that underlie four drivers. The analysis produced a ranking of the ten factors which provides a better understanding of their importance than when the drivers are directly ranked. It is anticipated that shedding light on these factors will help in the process of decision-making because the information is more detailed and more practical to use. For example, if a company considers customer demand to be an important driver for its sustainability agenda, then for this company to make informed decisions it is useful to understand the factors that support this driver and to investigate them further.

Ranking the factors was based on the principle of statistical control where variation is an indication of a problem which, when controlled, will provide an opportunity for improvement. If a factor, such as Six Sigma implementation varies between companies where some use Six Sigma extensively and some do not use it at all, an investigation into why Six Sigma is not used might yield an opportunity for improvement and benchmarking should commence.

The competitiveness driver was found to be one of the strongest drivers of SM, as two of its underlying factors rank 1st and 3rd. This indicates that special attention should be given to Lean and Six Sigma to attain SM. Supply chain integration was also found to be an important factor and, thus, should be promoted and made more effective.

This paper has sought to make the following contributions to the SM literature. Firstly, it draws attention to the importance of studying the factors that underlie SM drivers. Secondly, and uniquely, it has uniquely utilised a statistical technique to rank factors based on the principle that variation control represents an opportunity for improvement. This paper may encourage future research to undertake broader studies to include more factors, as the current study was limited to only a few factors where data were available from limited survey data.

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Tables

Table 1. Drivers of SM with some examples and the factors investigated in this study (adapted from [9].

Drivers	Cases	Supporting Factors under study	Rank
Competitiveness	(Better process performances, higher product quality, higher efficiency, competing with best practices in sector, etc.)	Lean Manufacturing, Six Sigma.	1
Incentives	(Investment subsidies, awards, R&D support, tax exemptions, duty free imports, etc.)		2
Organizational resources	(Availability of financial resources and skilled staff to implement programs.)	Annual spending on environmental programs	3
Technology	(Opportunities, advantages and performance of available green and efficient technology)		4
Cost savings	(Reduction of energy consumption, reduction in virgin material use, less waste, etc.)		5
Top management commitment	(Management, owner or investors are highly committed to enhance environmental performance, ethics, social values, etc.)		6
Customer demand	(Demand for environmentally friendly products)	Market competition, market concentration, importance of env.-friendly products to win orders, bargaining power of customers	7
Supply chain pressure	(Demand by suppliers, distributors, OEM, compliance with legislation in global markets)	Level of supply chain integration, bargaining power of suppliers	8
Public image	(Importance of a positive public perception of company, green image, etc.)		9
Future legislation	(Expected development of stricter laws, increased level of enforcement.)		10
Current legislation	(Pollution control norms, landfill taxes, emission trading, polluted water discharge norms, eco-label, etc.)		11
Public pressure	(Local communities, politicians, NGOs, media, insurance companies, banks, etc.)		12
Peer pressure	(Trade and business associations, networks, experts, etc.)		13

Table 2. Factors under study and the drivers they support

Driver	Underling Factors
Customer demand	1-Market competition 2-Market concentration 3-Importance of envi.-friendly products 4-Bargaining power of customers 5-Company size
Organizational resources	6-Spending on envi. programs -Company size*
Cost savings	7-Lean Manufacturing 8-Six Sigma
Competitiveness	-Lean Manufacturing* -Six Sigma*
Supply chain pressure	9-Level of supply chain integration 10-Bargaining power of suppliers -Company size*

* Some factors support more than one driver

Table 3. Total Variance Explained. Main components in bold face

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	**3.488**	**34.876**	**34.876**
2	**1.885**	**18.855**	**53.731**
3	**1.593**	**15.931**	**69.662**
4	**1.014**	**10.135**	**79.797**
5	.588	5.879	85.677
6	.447	4.470	90.147
7	.392	3.920	94.066
8	.319	3.189	97.255
9	.159	1.592	98.848
10	.115	1.152	100.000

Extraction Method: Principal Component Analysis.

Table 4. Factor ranking from the Rotated Component Matrix[a]. Factors with significant correlation to their components are in bold face.

Factor	Component			
	1	2	3	4
The level of implementation of Six Sigma	**.875**	.222	.200	.163
The level of supply chain integration	**.847**	-.112	.203	.101
The level of implementation of lean manufacturing	**.792**	.213	-.179	.076
Market competition level	-.084	**.919**	.217	.005
Importance of environmentally-friendly products to win orders	.192	**.864**	-.193	-.026
Size of business	.434	**.632**	.413	-.004
Market Concentration	.134	.119	**.910**	.058
Spending on environmental improvements	.279	.034	-.236	**.816**
Bargaining power of customers	-.343	-.129	.431	**.648**
Bargaining power of suppliers	.368	.029	.411	**.646**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]
a. Rotation converged in 8 iterations.

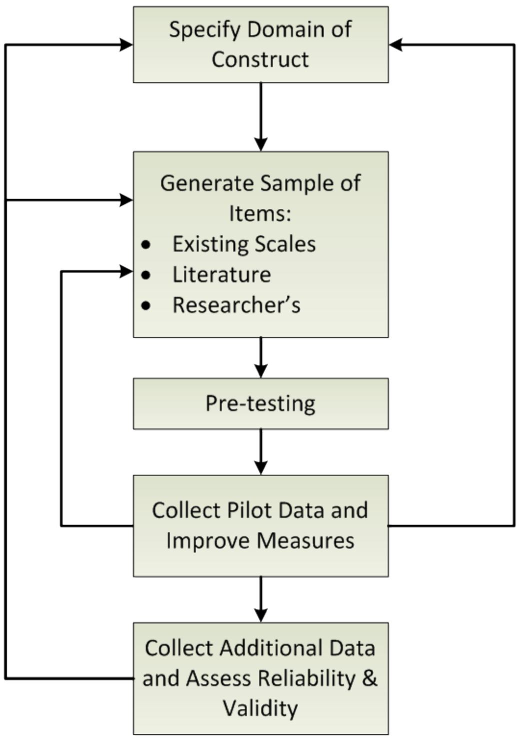

Figure 1. A framework for developing measurement scales.
Adapted from [28]