Sustainability associated with packaging products and systems is not a new concept but is gaining momentum. The perception of its core message remained ambiguous for implementation of sustainability in the packaging domain, pressure is also increasing to improve the performance of the packaging systems through the implementation of existing concepts and tools for realizing sustainability. A more integrated and definite approach is essential to meet future society and industry challenges within the context of packaging sustainability.

Protective packaging systems are affected by multiple elements throughout entire life cycle. They have to meet packaging process requirements, distribution efficiency requirements, environmental requirements, economic requirements and social requirements as well. There is increasing recognition that multi-criteria evaluation techniques are essential to create a sound protective packaging system in practice. Particularly, it is necessary to increase the knowledge to select the protective packaging systems that optimally meet social and economical as well as environmental performance requirements in product supply chain.

This dissertation research explored approach to sustainability assessment (SA) and attempted to assess sustainability attributes of the protective packaging system by the SA for optimization purpose. The research aims are: First, to better understand environment issues relevant to the protective packaging system in the supply chain; Second, to gain insights into definite concept of sustainable protective packaging system and associated multi-criteria system; and Third, to develop methodological approaches to SA models for guiding stakeholders to optimize the protective packaging system within the supply chain for promoting sustainability.

The dissertation research covers: (1) Identifying sustainable protective packaging system and related indicators through a critical review based on international literature and investigation of protective packaging design techniques with emphasis on interrelationships between product, material, transport and regulatory characteristics and requirements; environmental impact evaluation techniques; multi-criteria evaluation techniques; and sustainable packaging design techniques; (2) Establishing methodological approaches towards the development of multi-criteria system and multi-criteria evaluation models taking into account an
integral consideration of product, cushioning system and transport packaging characteristics and requirements under sustainable packaging principles. The proposed approaches to the SA for optimizing the protective packaging systems have been developed to meet supply chain requirements in this study. Quantitatively, the approaches measure multiple aspects of performance for the protective packaging systems with regards to social, economic/commercial and environmental aspects and integrates the results into a sustainability indicator/index (SI) or sustainability score (SC) for directly comparing the overall efficiency of packaging solutions. In particular, the social performance of the protective packaging systems is identified and quantified, based upon quality function deployment. The all-round evaluation tends to assist in optimum selection and indication of potential improvements in protective packaging designs; (3) Making survey on the multi-criteria system of sustainable protective packaging by questionnaires issued to related packaging and logistics companies; (4) Validating the multi-criteria evaluation models by testing their applicability and capability for typical variations of protective packaging systems as well as the robustness of models through various case studies, including studies on SA of protective cushioning for gas appliance, SA of protective cushioning for CD receiver, SA of logistics-oriented protective packaging for transporting turbochargers, multidimensional life cycle assessment on various molded pulp production systems and multi-criteria evaluation of protective packaging enterprises; (5) Writing and submitting manuscripts for publication and presentation.

For the dissertation research, 10 full-text refereed papers have been published in relevant peer reviewed journals, and 3 abstract-refereed papers regarding the research have been presented at international conferences and national conference. The doctoral thesis is organized by nine chapters as follows.

Chapter 1 of the thesis provides a general introduction about the research background, definite research questions, aims, objectives, methodology and outline of the thesis. A brief introduction to a critical review based on international literature about current packaging evaluation techniques is also included in the Chapter 1, which concentrated on describing and comparing related traditional environmental accounting techniques,
environmental impact evaluation techniques and impact indicator techniques used in the packaging area.

Chapter 2 of the thesis begins with a discussion and identification of what the concept of sustainable packaging system is based on literature review and investigation. Then, sustainability definition for the protective packaging system is described in the Chapter 2. The sustainability definition was given for laying foundation to following quantitative evaluation.

Chapter 3 and Chapter 4 introduce methodological approaches towards the development of multi-criteria system and multi-criteria evaluation models taking into account an integral consideration in multiple aspects of performance of sustainable protective packaging system. In this research, specific model was designed to serve specific player who work in the field of protective packaging, based upon grounded theories and developed principles. Model A, B and C used in the multi-criteria evaluation were created for guiding designer (and user), manufacturer and strategy decision-maker of the protective packaging systems respectively. These models can be used to assist in identifying potential improvements and new designs of the protective packaging systems in practice. The proposed multi-criteria system and evaluation models which subsequently are validated by performing selected case studies are presented in Chapters 5 through 8 later. The case studies represent the typical variation in the protective packaging systems.

Chapter 5 and Chapter 6 report the findings of multi-criteria evaluation of protective cushioning and logistics-oriented protective packaging by adopting the proposed SA method. The studies aim at comparing sustainability between protective cushioning or protective packaging within the product supply chain by the SA with transparent analysis. The SA measures various performance of the protective cushioning or protective packaging with regard to social, economic and environmental aspects and produces quantitative results (in monetary units), and then indicates the sustainability of the protective cushioning or protective packaging using a single SI. In the SA, a newly developed indicator representing social aspect of the protective cushioning or protective packaging, named real value added (RVA), was based upon quality function deployment (QFD) method; life-cycle impact assessment method based on endpoint modeling (LIME) was mainly adopted for measuring environmental impacts. Two types of protective cushioning for packaging a gas appliance, two new protective cushioning designs for a CD receiver (for car use only) and single-use and ten-time reusable packaging schemes for transporting a batch of turbochargers were assessed respectively as case study demonstration. The results showed advantages and disadvantages of the cases. The optimum selections for the cases were identified by the SA.

Chapter 7 reports the findings of multi-criteria evaluation of protective packaging production system by using a multidimensional life cycle assessment
The studies aim at detecting the problems in the production system by the proposed MLCA with transparent analysis and evaluating overall efficiency of the production system in a direct way. Three existing molded pulp production systems of industrial packaging were assessed. The LIME was adopted for indicating environmental burdens of the evaluation targets and three European models, named Eco-indicator’95, Ecopoint and Environmental Priority Strategies (EPS), were also used for validating the results. Finally, the multi-criteria evaluation not only showed main environmental impacts brought by the molded pulp production systems, but also indicated overall benefits of the evaluation targets with considerations in technical and economic aspects as well. The optimum for the cases was identified by calculating a newly developed SI.

Chapter 8 of the thesis deals with multi-criteria evaluation of protective packaging enterprises. A life cycle assessment (LCA) system suited for evaluating molded pulp packaging enterprises was investigated and demonstrated by case studies. It included considerations for environmental, economic and technological factors affecting the development of the enterprises. An analytic hierarchy process (AHP) hierarchy and associated matrices were used to effectively reflect the actual situation. The AHP-based multi-criteria evaluation model is a quantitative and qualitative analysis method which evaluates the molded pulp enterprises from investment for factory construction to manufacture processes of molded pulp packaging product, which emphasis on integrating and interpreting a large amount of complex data into user-friendly indicators. The optimum for the cases was identified by calculating SC.

Systematical approaches to the multi-criteria evaluation for selecting sustainable
protective packaging systems were structured and validated through various case studies in the research, but they still need to be updated further. In Chapter 9, last section of the thesis, provides summary on the dissertation research and features suggestions for future research initiatives in this area.