Stage 1: Determining the potential performance measures in managing warehouse operations - Content and construct validity analysis

Performance measures from a literature review and categorising them using Q-Sort method

Validation of performance categories

Stage 2: Establishement of relative weight of each performance measure

Fuzzy sets for each performance measure

Analytical hirarchical process (AHP) for prioritizing each performance measure

Relative weights of each performance measure under four categories (Accuracy, Resource utilisation, Finacial outcome, and Responsivness and Flexibility

Figure 1: Hybrid research methodology

Table 1: Performance measures in managing warehouse operations

Warehouse Performance Indicators	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[j]	[k]	[l]	[m]	[n]	[o]	[p]	[q]	[r]	[s]	[t]	[u]	[v]	[w]	[x]	[y]	[z]	[aa]	[bb]	[cc]	Total
Inventory accuracy		x									x	x	x								x	x	x		x	x				9
Accuracy in order picking		x						x										x	x		x	x								6
Accuracy in order Shipping		x		x																	x	x								4
% product transferred without transaction errors	x										x														x			x		4
Inventory obsolescence																							x		x					2
% orders / lines received with correct shipping documents	x																											x		2
Capacity utilization				x	x	x					x		x	x		x	x	x	x		x		x		x		x			13
Equipment utilization							x				x			x											x	x				5
Labour productivity and Labour utilization	x					x	x	x						x					x				x						x	8
Information availability and stability	x			x							x		x								x		x	x	x				x	9
Shipping Cost	x	x	x	x										x							x	x			x	x	x		x	11
Inventory onhand	x			x	x								x									x					x	x		7
Product damage rate										x	x										x	x								4
Insurance price											x																		x	2
Shortage Cost				x																		x					x			3
Maintenance Cost								x								x														2
Order Cycle time					x			x			x		x	x		x	x		x			x			x				x	11
On-time delivery					x						x	x		x	x	x	x	x	x		x	x							x	12
Responsiveness to urgent deliveries										x			x																	2
Unloading/Loading Time								x													x									2
Tracksibility					x		x																							2
Average lateness of order																x												x		2
Transporation Speed			x											x		x	x				x	x							x	7
Customer query time	x									x			x									x						x		5
In-transit time																					x							x		2
Number of stockouts	x										x											x			x	x				5
Product variety																						x						x		2
Order size flexibility										x													x							2
Stock Turn over	x			x	x						x	x							x			x				x				8
Carrier reliability										x											x					x				3
Delivery flexibility														x											x			x		3
Flexibility of service systems to meet										x															x					2

[a] Ganesan et., al, 2009   [b] Baker and Halim, 2007   [c] Bennett and Klug,2012   [d] Birou et al. 2011   [e] Chae, 2009   [f] Colson and Dorigo, 2004   [g] Evangelista et al, 2012

[h] Gu et al, 2007   [i] Gu et al, 2010   [j] Gunasekaran et al, 2001   [k] Gotzamani et al, 2010   [l] Hoek, 2001   [m] Jeffers, 2010   [n] Green Jr., et al, 2008

[o] de Koster and Warffemius, 2005   [p] Meepetchdee and Shah, 2007   [q] Milgate, 2001   [r] Petersen, 2002   [s] Petersen et al, 2005   [t] Poon et al, 2009

[u] Rahman and Wu, 2011   [v] Banomyong and Supatn, 2011 [w] Sheu et al, 2006   [x] Sohn et al, 2007   [y] Visich et al, 2009   [z] Wouters and Sportel, 2005

[aa] Yang et al, 2012   [bb] Yu et al, 2012   [cc] Zailani et al, 2005

Table 2: Cohen Kappa of three industries

Category	K_j	$Var(K_j)$	$\dfrac{K_j}{SE(K_j)}$
Overall	0.7509	0.0001812	55.785
Category A	0.8175	0.0044636	12.236
Category B	0.7317	0.0034087	12.532
Category C	0.7504	0.0049685	10.646
Category D	0.7576	0.0067133	9.247
N/A	-0.0140	0.0017136	-0.339

Table 3: Cohen Kappa of manufacturing industry

Category	K_j	$Var(K_j)$	$\dfrac{K_j}{SE(K_j)}$
Overall	0.8031	0.0004675	37.144
Category A	0.8752	0.0157156	6.981
Category B	0.7349	0.0127920	6.497
Category C	0.7783	0.0167229	6.018
Category D	0.8580	0.0205613	5.984
N/A	-0.0133	0.0163802	-0.104

Table 4: Cohen Kappa of retail (after 2 rounds)

Category	K_j	$Var(K_j)$	$\dfrac{K_j}{SE(K_j)}$
Overall	0.6666	0.0011850	19.365
Category A	0.7427	0.0336788	4.047
Category B	0.7020	0.0309531	3.990
Category C	0.6621	0.0370067	3.442
Category D	0.6517	0.0430981	3.139
N/A	-0.0213	0.0476187	-0.098

Table 5: Cohen Kappa of 3PLs

Category	K_j	$Var(K_j)$	$\dfrac{K_j}{SE(K_j)}$
Overall	0.6881	0.0008755	23.256
Category A	0.7409	0.0249595	4.690
Category B	0.6842	0.0214737	4.669
Category C	0.7159	0.0261287	4.429
Category D	0.6804	0.0339800	3.691
N/A	-0.0179	0.0316353	-0.100

Table 6: Qualification of practitioners joining in Fuzzy AHP

Business Type	Assessor	Job Position	Working Experience (years)
Manufacturing	Assessor # 1	Warehouse Ass. Manager	10
	Assessor # 2	Engineer	8
	Assessor # 3	Process Analysis Engineer	5
	Assessor # 4	Factory Manager	24
	Assessor # 5	Warehouse supervisor	3
	Assessor # 6	Procurement Engineer	3
	Assessor # 7	Warehouse Manager	12
	Assessor # 8	General Manager	15
Third Party Logistics Providers (3PLs)	Assessor # 9	Manager	5.5
	Assessor # 10	Supervisor	2
	Assessor # 11	General Manager	2
	Assessor # 12	Supervisor	2
	Assessor # 13	Assistant Manager	10
	Assessor # 14	Manager	3
Retails	Assessor # 15	Manager	14
	Assessor # 16	Manager	5
	Assessor # 17	Supervisor	2
	Assessor # 18	Manager	11
	Assessor # 19	Manager	3
	Assessor # 20	General Manager	10
		Avg. working experience	7.5
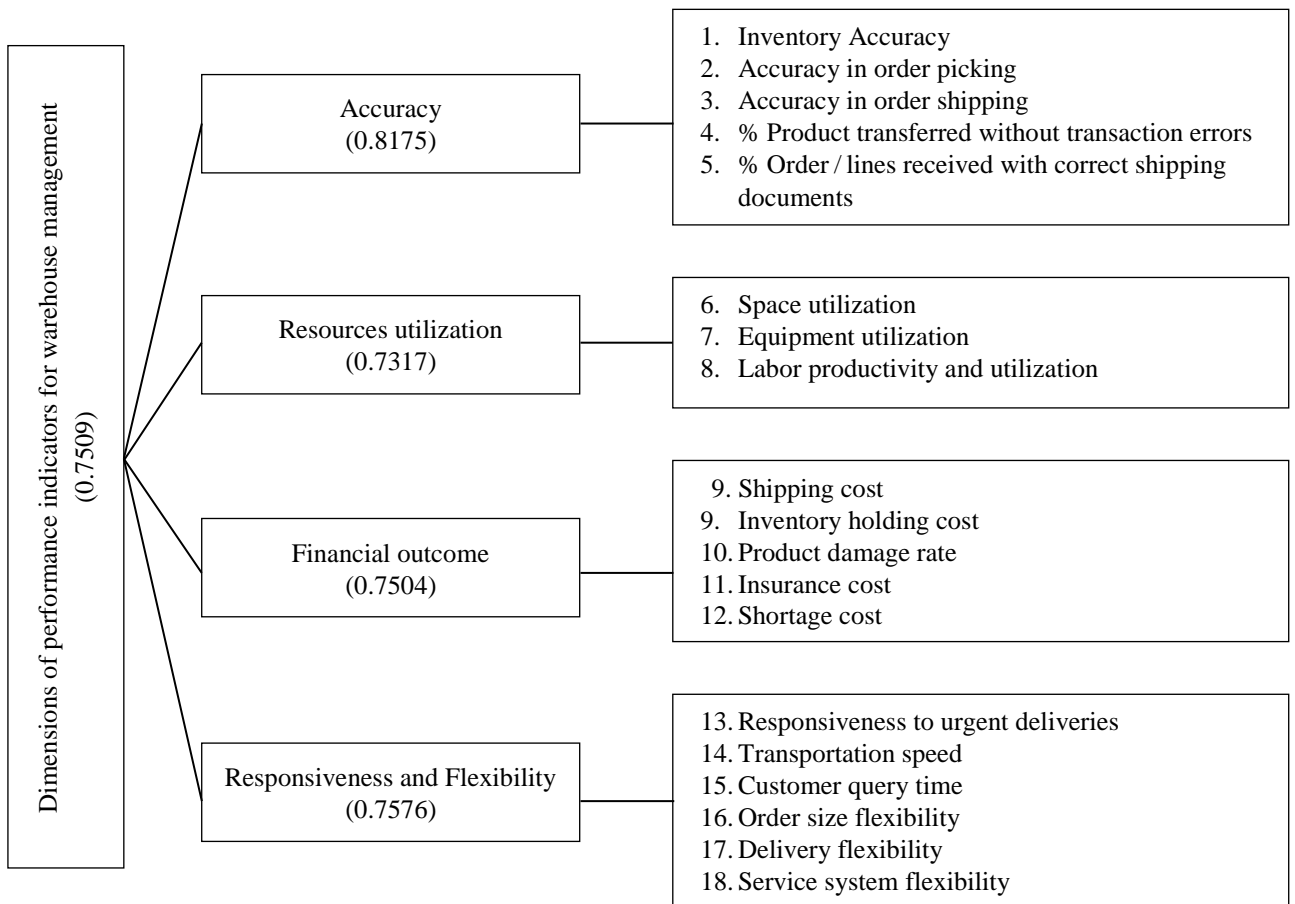
Figure 2: Overall result from Q-Sort method

| Priority of warehouse performance measurers | Goal level |

| Accuracy dimension | Resources utilization dimension | Financial outcome dimension | Responsiveness and Flexibility dimension | Category or criteria level |

Accuracy dimension
1. Inventory Accuracy
2. Accuracy in order picking
3. Accuracy in order shipping
4. % Product transferred without transaction errors
5. % Order / lines received with correct shipping documents

Resources utilization dimension
6. Space utilization
7. Equipment utilization
8. Labour productivity and utilization

Financial outcome dimension
9.. Shipping cost
10. Inventory holding cost
11. Product damage rate
12. Insurance cost
13. Shortage cost

Responsiveness and Flexibility dimension
14. Responsiveness to urgent deliveries
15. Transportation speed
16. Customer query time
17. Order size flexibility
18. Delivery flexibility
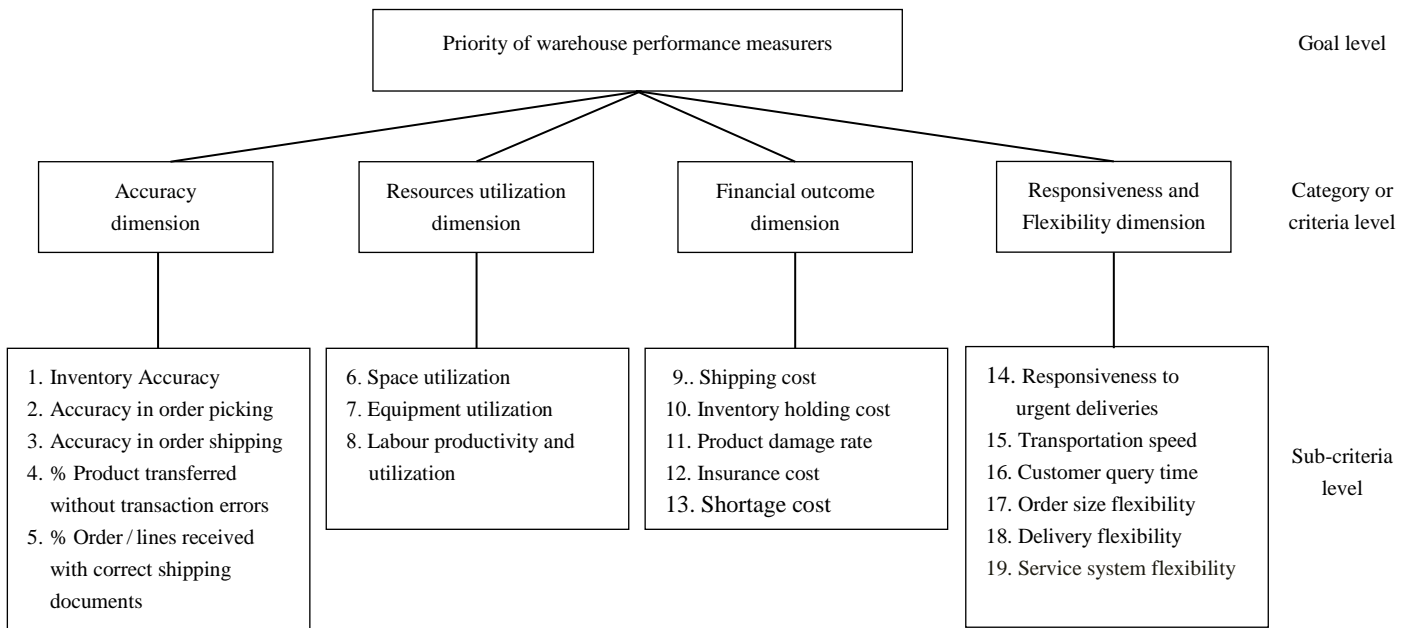19. Service system flexibility

Sub-criteria level

Figure 3: Analytic hierarchy structures of warehouse performance measures

Table 7: Relative weights of four categories of performance measures

	Indicator dimensions	Manufacturing	3PLs	Retails	Total 3 Business
A	Accuracy	0.138	0.240	0.269	0.223
B	Resource utilization	0.308	0.248	0.091	0.232
C	Financial outcome	0.457	0.344	0.320	0.370
D	Responsiveness and flexibility	0.096	0.168	0.320	0.176

Table 8: Relative weights of five measures within "Accuracy" category

Accuracy dimension		Manufacturing	3PLs	Retails	Total 3 Businesses
A1	Inventory Accuracy	0.213	0.182	0.124	0.178
A2	Accuracy in order picking	0.159	0.207	0.173	0.175
A3	Accuracy in order shipping	0.171	0.188	0.210	0.182
A4	% of product transferred without transaction errors	0.212	0.197	0.247	0.232
A5	% of order / lines received with correct shipping documents	0.245	0.225	0.247	0.232

Table 9: Relative weights of three measures within "Resources utilization" category

Resources utilization dimension		Manufacturing	3PLs	Retails	Total 3 Businesses
B1	Space utilization	0.165	0.278	0.043	0.183
B2	Equipment utilization picking	0.505	0.363	0.600	0.469
B3	Labor productivity and utilization	0.330	0.359	0.358	0.348

Table 10: Relative weights of five measures within "Financial outcome" category

Financial outcome dimension		Manufacturing	3PLs	Retails	Total 3 Businesses
C1	Shipping cost	0.204	0.228	0.211	0.211
C2	Inventory holding cost	0.105	0.124	0.210	0.153
C3	Product damage rate	0.194	0.202	0.134	0.177
C4	Insurance cost	0.275	0.257	0.223	0.247
C5	Shortage cost	0.222	0.189	0.223	0.211

Table 11: Relative weights of six measures within "Responsiveness and flexibility" category

Responsiveness and flexibility dimension		Manufacturing	3PLs	Retails	Total 3 Businesses
D1	Responsiveness to urgent deliveries	0.190	0.232	0.128	0.178
D2	Transportation speed	0.110	0.173	0.195	0.153
D3	Customer query time	0.142	0.005	0.209	0.142
D4	Order size flexibility	0.217	0.258	0.169	0.210
D5	Delivery flexibility	0.143	0.158	0.169	0.149
D6	Service system flexibility	0.199	0.173	0.129	0.167

Table12: Relative weights of overall performance measures and categories

Category level	Weight		Performance measure level		Weight
A. Accuracy	0.223	A1	Inventory Accuracy		0.178
		A2	Accuracy in order picking		0.175
		A3	Accuracy in order shipping		0.182
		A4	% of product transferred without transaction errors		0.232
		A5	% of order / lines received with correct shipping documents		0.232
B. Resources Utilization	0.232	B1	Space utilization		0.183
		B2	Equipment utilization picking		0.469
		B3	Labor productivity and utilization		0.348
C. Financial outcome	0.370	C1	Shipping cost		0.211
		C2	Inventory holding cost		0.153
		C3	Product damage rate		0.177
		C4	Insurance cost		0.247
		C5	Shortage cost		0.211
D. Responsiveness and flexibility	0.176	D1	Responsiveness to urgent deliveries		0.178
		D2	Transportation speed		0.153
		D3	Customer query time		0.142
		D4	Order size flexibility		0.210
		D5	Delivery flexibility		0.149
		D6	Service system flexibility		0.167