Chapter 6 Application

In this chapter, a real case study from communication industry is presented. We will show that the VPRS theory using our proposed procedures can be applied to reduce the radio frequency (RF) test items in mobile phone manufacturing.

6.1 Problem Description

Personal wireless communication is one of the fastest growing fields in the communications industry. The technology employed by mobile telecommunications is advancing rapidly with shorter product life cycles. In recent years, dual band (GSM/DCS) mobile phone users have been steadily increasing. Furthermore, the diffusion of mobile technology is likely to persist well into this decade. Therefore, mobile phone manufacturers require an effective method to reduce the mobile phone manufacturing time in advance of further market demand.

The global system mobile (GSM) and digital communication system (DCS) are based on different techniques, involving communication methods such as time division multiplex access and discontinuous transmission and power control strategies. The dual band mobile phone manufacturing procedure is shown in Figure 6.1. From Figure 6.1, we know that a radio frequency (RF) functional test needs more operation time than other manufacturing processes. The RF test aims to inspect if the mobile phone receive/transmit signal satisfies the enabled transmission interval (ETI) protocol on different channels and power levels. In order to ensure the quality of communication of mobile phones, the manufacturers usually add extra inspection items, such as several different frequency channels and power levels, resulting in inspection time being increased and the test procedure becoming a bottleneck.

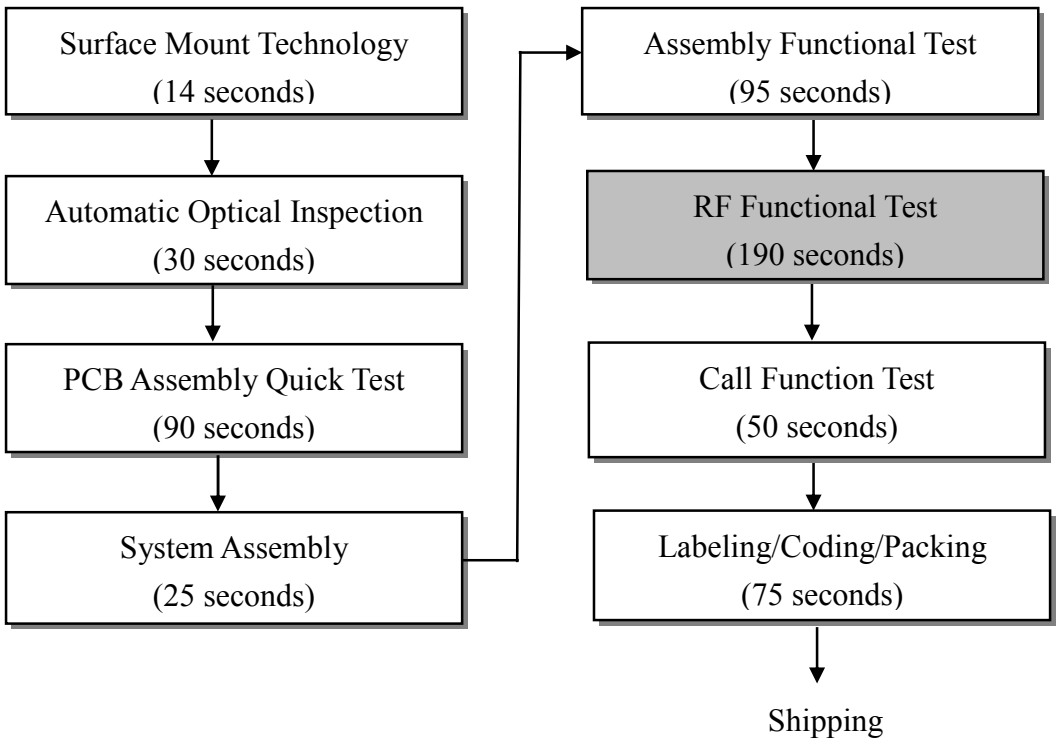

Figure 6.1 A Manufacturing Process of a Mobile Phone

6.2 Implementation

For the purpose of an empirical implementation, we collected data from a mobile phone manufacturer located in Taoyuan, Taiwan. Each RF functional test includes nine test items and they are: the power versus time (PVT; symbol: A), the power level (TXP; symbol: B), the phase error and frequency error (PEFR; symbol: C), the bit error rate (BER-20; symbol: D), the bit error rate (BER-(-102); symbol: E), the ORFS-spectrum due to switching transient (ORFS_SW; symbol: F), the ORFS-spectrum due to modulation (ORFS_MO; symbol: G), the Rx level report accuracy (RXP_Lev_Err; symbol: H), and the Rx level report quality (RXP_QUALITY; symbol: I). Each test item according to different channels and power levels has separated several test attributes. Each test attributes' form is to be represented as: test item-channel-power level, which has a total of 62 test attributes including 27 continuous value test attributes and 35 discrete value test attributes.

In this study 168 objects are collected, and these objects are separated into a training set that includes 112 objects (84 objects that passed; 28 objects that failed) and a test set that includes 56 objects (28 objects that passed; 14 objects that failed).

6.2.1 Discretization

Since the VPRS model needs the data in a categorical form, the continuous attributes must be discretized before the VPRS analysis is performed. By using extended Chi2 algorithm, the number of continuous attributes is reduced from 27 to 20. The results are listed in Table 6.1. Therefore, the RF function test has 55 test attributes (35 discrete attributes and 20 discretization attributes) for further study.

Table 6.1 Condition Attributes' Ranges for Extended Chi2 Algorithm

	Range '1'	Range '2'	Range '3'	Range '4'	Range '5'	Range '6'	Range '7'	Range '8'	Range '9'	Range '10'	Range '11'	Range '12'	Range '13'
B-10-5	30.62 ~31.92	31.98 ~32.11	32.12 ~32.13	32.14 ~32.36	32.37 ~32.45	—	—	—	—	—	—	—	—
B-114-5	30.21 ~31.33	31.46 ~31.67	31.68 ~31.82	31.83	31.84 ~31.85	31.86 ~31.87	31.88 ~31.89	31.90	31.91 ~32.11	32.13 ~32.17	—	—	—
B-522-0	23.49 ~25.58	28.39 ~28.44	28.45	28.46 ~28.62	28.63 ~28.84	28.85	28.86 ~28.97	28.99 ~29.01	29.02 ~29.07	29.08 ~29.09	29.10 ~29.13	29.14 ~29.35	29.37
B-688-15	-3.01 ~-0.63	0.69 ~0.94	0.95	0.96 ~1.15	1.16 ~1.19	1.21 ~1.32	—	—	—	—	—	—	—
B-688-0	23.45 ~26.27	28.95 ~29.07	29.08 ~29.20	—	—	—	—	—	—	—	—	—	—
B-688-3	19.37 ~23.57	23.68 ~23.83	23.84 ~23.89	23.90 ~24.06	—	—	—	—	—	—	—	—	—
B-688-7	11.34 ~14.74	15.11 ~15.50	15.51	15.52 ~15.70	—	—	—	—	—	—	—	—	—
B-72-11	19.35 ~20.54	20.55 ~21.07	—	—	—	—	—	—	—	—	—	—	—
B-72-19	3.31 ~5.24	5.28 ~5.33	5.34 ~5.35	5.36 ~5.64	—	—	—	—	—	—	—	—	—
B-72-5	30.25 ~31.61	31.62	31.63 ~31.68	31.69 ~31.74	31.75 ~31.82	—	—	—	—	—	—	—	—
B-72-7	27.51 ~28.89	28.91 ~28.98	28.99 ~29.36	—	—	—	—	—	—	—	—	—	—
B-875-0	25.98 ~27.98	28.06 ~28.28	28.29 ~28.64	28.65 ~28.66	28.67 ~28.69	28.72	28.73 ~28.87	28.91 ~29.08					
B-965-5	30.70 ~32.46	32.48 ~32.99	33.00 ~33.26	—	—	—	—	—	—	—	—	—	—
E-10-5	0.00000 ~0.07284	0.11655 ~3.07401	—	—	—	—	—	—	—	—	—	—	—
E-114-5	0.00000 ~0.04371	0.05828 ~0.07284	0.08741 ~3.74300	—	—	—	—	—	—	—	—	—	—
E-522-0	0.07284	0.10198 ~0.30594	0.32051	0.33508 ~0.49534	0.99068 ~3.88986	—	—	—	—	—	—	—	—
E-688-0	0.00000 ~0.07284	0.08741 ~0.21853	0.32051 ~3.24883	—	—	—	—	—	—	—	—	—	—
E-72-5	0.00000 ~0.0291	0.0437	0.0583 ~0.1020	0.1603 ~3.3217	—	—	—	—	—	—	—	—	—
E-875-0	0.08741 ~0.58275	1.15093 ~3.77331	—	—	—	—	—	—	—	—	—	—	—
E-965-5	0.00000 ~0.04371	0.05828 ~0.17483	0.43706 ~3.52564	—	—	—	—	—	—	—	—	—	—

6.2.2 Using the VPRS Model

In this study the objects have been classified into one of two categories, 0 (passed) and 1 (failed). By formula (4.1), the precision parameter (β) value is equal to 0. According to the process of finding β-reducts in section 4.2, the full set of β-reducts associated with the information system is given in Table 6.2. Since the β-reduct {*B*-114-5, *E*-114-5, *H*-965-(-102), *B*-522-0, *B*-688-15} has the least number of attributes and the least number of combinations of values of its attributes, it is selected for further study. The $M(S)$-information system for this β-reduct will be: {*B*-114-5, *E*-114-5, *H*-965-(-102), *B*-522-0, *B*-688-15}. That is to say, the number of test attributes is reduced from 55 to 5. Based on the $M(S)$-discernibility matrix constructed by the $M(S)$-information system, the superfluous values of the test attributes can be eliminated and the extracted rules are listed in Table 6.3. We can see that the objects of the test set at rule 3, rule 9, rule 10, rule 11, rule 12, and rule 16 are null, while rule 6, rule 13, rule 14, and rule 15 show only one object in the test set. Since these rules are not a matter for the judgment of the product, they are deleted. The final extraction rules are listed in Table 6.4. From Table 6.4 we know that the accuracy of the extraction rules in the test set is 98.21% (55/56).

Table 6.2 β-reducts Associated with the Information System

β-reduct			
1	{B-114-5, H-114--102, B-522-0, I-522-(-102), B-688-15}	15	{E-72-5, B-114-5, H-114-(-102), B-522-0, I-522-(-102), H-875-(-102)}
2	{B-72-7, B-114-5, H-114-(-102), B-522-0, B-688-15}	16	{B-114-5, H-114-(-102), B-522-0, I-522-(-102), H-875-(-102), I-875-(-102)}
3	{B-10-5, B-114-5, H-114-(-102), B-522-0, B-688-3}	17	{B-72-7, B-114-5, H-114-(-102), B-522-0, E-688-0, H-875-(-102)}
4	{B-114-, H-114-(-102), B-522-0, E-522-0, B-688-15}	18	{H-10-(-102), B-72-7, B-114-5, B-522-0, E-688-0, H-875-(-102)}
5	{B-72-19, B-114-5, H-114-(-102), B-522-0, B-875-0}	19	{H-10-(-102), B-72-5, E-72-5, B-114-5, B-522-0, H-875-(-102)}
6	{B-114-5, E-114-5, H-965-(-102), B-522-0, B-688-15}	20	{H-10-(-102), B-72-5, B-114-5, B-522-0, H-875-(-102), I-875-(-102)}
7	{B-114-5, H-114-(-102), B-522-0, I-522-(-102), B-688-3, I-875-(-102)}	21	{H-10-(-102), B-72-5, B-114-5, B-522-0, H-688-(-102), I-875-(-102)}
8	{B-72-5, E-72-5, B-114-5, H-114-(-102), B-522-0, G-522-0}	22	{B-72-5, B-114-5, H-114-(-102), B-522-0, G-522-0, B-875-0}
9	{B-72-7, B-114-5, H-965-(-102), B-522-0, E-688-0, I-875-(-102)}	23	{H-10-(-102), B-72-19, B-114-5, C-965-5, B-522-0, B-688-15}
10	{H-10-(-102), B-72-5, E-72-5, B-114-5, H-114-(-102), B-522-0}	24	{H-10-(-102), E-72-5, B-114-5, B-522-0, I-522-(-102), F-875-0}
11	{B-72-5, E-72-5, B-114-5, H-114-(-102), B-522-0, B-688-0}	25	{H-10-(-102), C-72-5, B-114-5, E-114-5, B-522-0, I-522-(-102)}
12	{B-72-5, E-72-5, B-114-5, H-114-(-102), B-522-0, I-522-(-102)}	26	{H-10-(-102), G-72-5, B-114-5, E-114-5, B-522-0, I-522-(-102)}
13	{B-72-5, E-72-5, B-114-5, H-114-(-102), B-522-0, G-688-0}	27	{H-10-(-102), B-72-7, B-114-5, E-965-5, B-522-0, B-688-15}
14	{B-114-5, H-114-(-102), B-522-0, I-522-(-102), B-875-0, G-875-0}		

Table 6.3 Results of Rule Extraction (VPRS)

Method	Extraction Rules	Accuracy	
		Training Set	Test Set
VPRS	1. If 32.13≦B-114-5<31.46, then one has failed.	100% (5/5)	100% (4/4)
	2. If 31.46≦B-114-5≦31.82, 0≦E-114-50.07284, H-965-(-102) ≦7 and 28.46≦ B-522-0≦28.97, then one is passed.	95.12% (39/41)	95.83% (23/24)
	3. If H-965-(-102), then one has failed.	100% (5/5)	—
	4. If 31.68≦B-114-5≦31.82, 0≦E-114-5≦0.04731, H-965-(-102)=1 and 0.69≦B-688-15≦1.15, then one is passed.	100% (3/3)	100% (2/2)
	5. If 31.91≦B-114-5≦32.11, H-965-(-102) ≦1 and 0.69≦B-688-15≦1.15, then one is passed.	100% (20/20)	100% (6/6)
	6. If 31.91≦B-114-5≦32.11, H-965-(-102) =1 and 1.16≦B-688-15≦1.19, then one has failed.	100% (1/1)	100% (1/1)
	7. If 0.08741≦E-114-5, then one has failed.	100% (6/6)	100% (9/9)
	8. If 31.84≦B-114-5≦31.89, 28.46≦B522-0≦29.07 and 0.69≦B-688-15≦1.19, then one is passed.	100% (9/9)	100% (7/7)
	9. If 31.84≦B-114-5≦31.87, 28.86≦B-522-0 and 1.21≦B-688-15, then one has failed.	100% (2/2)	—
	10. If B-688-15=0.95, then one has failed.	100% (2/2)	—
	11. If 31.83≦B-114-5≦31.89 and 0.69≦B-688-15≦0.94, then one is passed.	100% (5/5)	—
	12. If 31.68≦B-114-5≦31.82, H965-(-102) ≦1 and 1.21≦B-688-15, then one is passed.	100% (2/2)	—
	13. If 31.88≦B-114-5 and H-965-(-102) ≦1 and 1.21≦B-688-15, then one is passed.	100% (2/2)	100% (1/1)
	14. If 0≦E-114-5≦0.07284, H-965-(-102) ≦2 and B-522-0≧28.63, then one has failed.	100% (4/4)	100% (1/1)
	15. If B-114-5≧31.90, 0.05828≦E-114-5≦0.07284, H965-(-102)=1 and 0.69≦B-688-15≦0.94, then one is passed.	100% (3/3)	100% (1/1)
	16. If 23.49≦B-522-0≦25.58 and B-688-15≦0.68, then one has failed.	100% (1/1)	—

Notes: 1. (/) indicates (number of correct instances/number of total instances).

2. "—" indicates the object in the set is null.

Table 6.4 Final Results of Rule Extraction (VPRS)

Method	Extraction Rules	Accuracy	
		Training Set	Test Set
VPRS	1. If 32.13≦B-114-5<31.46, then one has failed.	100% (5/5)	100% (4/4)
	2. If 31.46≦B-114-5≦31.82, 0≦E-114-50.07284, H-965-(-102) ≦7 and 28.46≦ B-522-0≦28.97, then one is passed.	95.12% (39/41)	95.83% (23/24)
	3. If 31.68≦B-114-5≦31.82, 0≦E-114-5≦0.04731, H-965-(-102)=1 and 0.69≦B-688-15≦1.15, then one is passed.	100% (3/3)	100% (2/2)
	4. If 31.91≦B-114-5≦32.11, H-965-(-102) ≦1 and 0.69≦B-688-15≦1.15, then one is passed.	100% (20/20)	100% (6/6)
	5. If 0.08741≦E-114-5, then one has failed.	100% (6/6)	100% (9/9)
	6. If 31.84≦B-114-5≦31.89, 28.46≦B522-0≦29.07 and 0.69≦B-688-15≦1.19, then one is passed.	100% (9/9)	100% (7/7)

Notes: (/) indicates (number of correct objects/ number of total objects).

6.2.3 Using the Decision Tree Approach

In this section the See 5 software package is used to perform the computation. The parameters of See5 utilize its default setting. The tree structure is shown in Figure 6.2, from which we know that *C*-965-5, *B*-688-3, *H*-965-(-102), *B*-688-0, *E*-114-5, and *G*-114-5 are important attributes of the RF functional test. The number of RF functional test attributes will be reduced from 55 to 6. The extracted rules are listed in Table 6.5. We know that the objects of the test set at rule 3 and rule 7 are null, while rule 2 and rule 4 show only one object in the test set. Since these rules are not a matter for the judgment of the product, they are deleted. The final extraction rules are listed in Table 6.6. In the test set, three objects do not match any of the rules and the accuracy of the extraction rules is 94.64% (53/56).

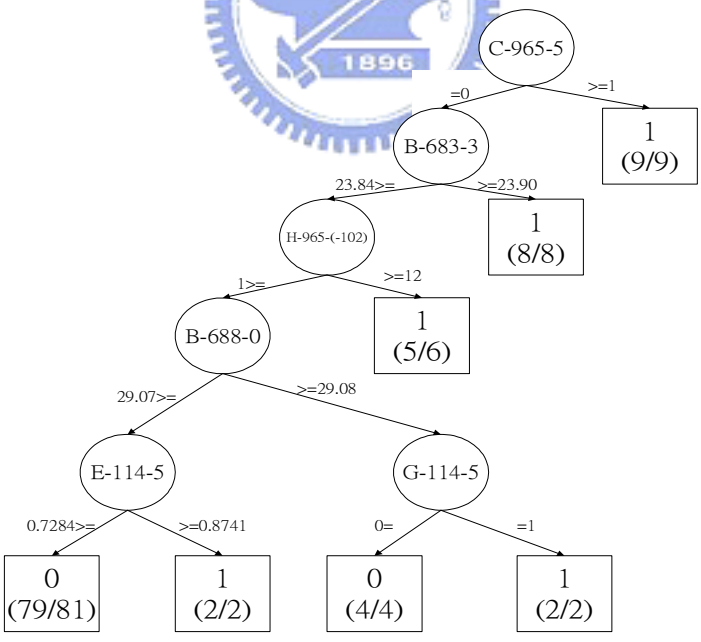

Figure 6.2 Tree Structure of the Information System

Table 6.5 Results of Rule Extraction (See 5 software)

Method	Extraction Rules	Accuracy	
		Training Set	Test Set
See 5	1. If C-965-5≧1, then one has failed.	100% (9/9)	100% (3/3)
	2. C-965-5 and B-688-3≧23.90, then one has failed.	100% (8/8)	100%(1/1)
	3. If C-965-5=0, B-688-3≦23.84 and H-965-(-102)≧12, then one has failed.	85.71%(6/7)	—
	4. If C-965-5=0, B-688-3≦23.84, H-965-(-102)≦1, B-688-0≧29.08 and G-114-5=0, then one is passed.	100% (4/4)	100% (1/1)
	5. If C-965-5=0, B-688-3≦23.84, H-965-(-102)≦1, B-688-0≧29.08 and G-114-5=1, then one has failed.	100% (2/2)	100% (8/8)
	6. If C-965-5=0, B-688-3≦23.84, H-965-(-102)≦1, B-688-0≦29.07 and E-114-5≧0.8741, then one has failed.	97.60 % (81/83)	100% (40/40)
	7. If C-965-5=0, B-688-3≦23.84, H-965-(-102)≦1, B-688-0≦29.07 and E-114-5≦0.8741, then one is passed.	100% (2/2)	—

Notes: 1. (/) indicates (number of correct instances/number of total instances).

2. "—" indicates that the object in the set is null.

3. In the test set, three objects do not match any of the rules.

Table 6.6 Final Results of Rule Extraction (See 5 software)

Method	Extraction Rules	Accuracy	
		Training Set	Test Set
See 5	1. If C-965-5≧1, then one has failed.	100% (9/9)	100% (3/3)
	2. If C-965-5=0, B-688-3≦23.84, H-965-(-102)≦1, B-688-0≧29.08 and G-114-5=1, then one has failed.	100% (2/2)	100% (8/8)
	3. If C-965-5=0, B-688-3≦23.84, H-965-(-102)≦1, B-688-0≦29.07 and E-114-5≧0.8741, then one has failed.	97.60 % (81/83)	100% (40/40)

Notes: 1. (/) indicates (number of correct instances/number of total instances).

2. In the test set, three objects do not match any of the rules.

6.2.4 A Comparison

The effectiveness of the VPRS model is conducted at the test line in the case company. Assume that the inspection accuracy of the original test procedure is 100%. According to Table 6.7, the implementation results under normal production over six weeks confirm that the overall inspection accuracies for the VPRS model and decision tree approach are 99.75% and 99.61%, respectively. This fact shows that the quality of the RF functional test will be not affected, when some unimportant test items are removed by using the VPRS model or the decision tree approach. The VPRS model outperforms the decision approach in terms of inspection accuracy. Moreover, the test

time of the original RF test procedure (62 test attributes) is 190 seconds, while the VPRS model (5 test attributes) is 34.5 seconds and the decision tree approach (6 test attributes) is 43.2 seconds. This leads to the number of RF test machines is reduced from 8 to 4, which saving equipment cost 6 million NT dollars (each machine cost is 1.5 million NT dollars) from implementation the VPRS model in RF test procedure. Those extracted rules that form Table 6.4 (or Table 6.6) will help a company to construct a knowledge base to train new engineers.

Table 6.7. A comparison of the VPRS model and decision tree

Week	VPRS		Decision Tree (See 5 software)	
	Pass instances accuracy (%)	Fail instances accuracy (%)	Pass instances accuracy (%)	Fail instances accuracy (%)
1	100% (639/639)	75% (6/8)	100% (639/639)	75% (6/8)
2	100% (1240/1240)	86.36% (19/22)	100% (1240/1240)	72.72% (16/22)
3	100% (316/316)	100% (2/2)	100% (316/316)	100% (2/2)
4	100% (108/108)	100% (2/2)	100% (108/108)	100% (2/2)
5	100% (198/198)	75% (3/4)	100% (198/198)	100% (4/4)
6	100% (305/305)	80% (4/5)	100% (305/305)	40% (2/5)
Overall	100% (2806/2806)	83.72% (36/43)	100% (2806/2806)	74.42% (32/43)
	99.75% (2842/2849)		99.61% (2838/2849)	

Notes: (/) indicates (number of correct instances/number of total instances).