

INTEGRATION OF SMED AND TRIZ IN IMPROVING PRODUCTIVITY AT
SEMICONDUCTOR INDUSTRY

KARTIK SREEDHARAAN KUMARESAN

UNIVERSITI TEKNOLOGI MALAYSIA

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In dedication to my beloved parents and wife

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ABSTRACT

A case study on a test handler's changeover process was conducted in a semiconductor organization (Intel Technology Sdn. Bhd.). The test handler being a constraint operation in the production supports the testing of two of the mainstream chipset products. Though the test handler is capable to support multiple chipset products but due to the equipment configuration complexity, the changeover process today requires an average 4 hours to fully complete. The long changeover duration degrades the overall productivity especially inability to meet customer demand timely, lower utilization and rising cost issues. These identified issues are potential factors that could impact the sustainability of the organization in long run. This case study focuses on improving the changeover process using techniques from Single Minute Exchange of Die (SMED) and Theory of Inventive Problem Solving (TRIZ). Both the techniques have individual strengths and weakness and thus the focus will be to integrate them to complement each other to enhance the changeover process duration further. Problems in the current process like non standard practices, complex hardware setup and waste activities that plagued today are process were identified and categorized accordingly. Later, appropriate techniques from SMED and TRIZ were proposed to counter these issues systematically. SMED will be used mostly for task simplification while TRIZ will be used for hardware part redesigns and overall process optimization. The end of mind of this study is to achieve a lean and optimized changeover process that can be performed below 30 minutes with no safety, quality or output concerns.

ABSTRAK

Kajian kes ini bertumpu amnya pada pengubahsuaian mesin di Intel Technology Sdn. Bhd yang merupakan pengeluar cip komputer terbesar di dunia. Mesin yang digunakan di operasi pemeriksaan cip silikon secara automatik ini mampu mengendali pelbagai jenis cip tetapi memerlukan pengubahsuaian tertentu. Proses pengubahsuaian mesin ini boleh memakan masa sehingga 4 jam untuk disiapkan sebelum digunakan balik untuk operasi. Disebabkan ini, organisasi ini mengalami kemerosotan produktiviti and juga kerugian kos-kos lain. Untuk mengatasi masalah ini, teknik-teknik daripada SMED and TRIZ diperkenalkan untuk menyelesaikan isu –isu seperti ketidakselarasan aktiviti dan penukaran alat ganti yang kompleks. Teknik SMED and TRIZ dikaji secara teliti sebelum dicadangkan untuk penyelesaian. Teknik-teknik SMED banyak digunakan untuk mempermudah activiti kerja dan teknik-teknik TRIZ banyak berguna untuk mereka bentuk alat ganti yang lebih mudah dan efiksyen untuk ditukar ganti. Cadangan-cadangan ini setelah dilaksanakan dapat membantu mengurangkan masa pengubahsuaian daripada 4 jam kepada 30 minit dengan tiada sebarang masalah kualiti, keselamatan ataupun pengeluaran.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xii
	LIST OF FIGURES	xiv
	LIST OF ABBREVIATIONS	xviii
1	INTRODUCTION	
1.1	Overview	1
1.2	Background of Problems	1
1.3	Statement of Problems and Justification	3
1.4	Objective of Study	3
1.5	Scopes	3
1.6	Significance of Study	4
1.7	Thesis Structure	4

2 LITERATURE REVIEW

2.1	Overview	5
2.2	Lean Manufacturing	5
	2.2.1 History and Background	7
	2.2.2 Lean Concepts	8
	2.2.3 Lean Tools	9
	2.2.4 The ‘bright side’ of Lean	10
	2.2.5 The ‘Anti’ Lean Sentiment	11
2.3	Optimization of Changeover Process	13
	2.3.1 Changeover and PM	14
	2.3.2 Benefits of Quick Changeover	15
	2.3.3 Alternatives to Quick Changeover	15
2.4	Single Minute Exchange of Die (SMED)	15
	2.4.1 Advantages of SMED	18
	2.4.2 Disadvantages of SMED	19
2.5	Theory of Inventive Problem Solving (TRIZ)	20
	2.5.1 History and Background	20
	2.5.2 Conceptual Basis of TRIZ	21
	2.5.3 Common TRIZ terminologies	24
	2.5.4 Tools in TRIZ field	25
	2.5.5 Application and Implementation of TRIZ	28
	2.5.6 Shortcomings of TRIZ	29
2.6	Summary	31

3 METHODOLOGY OF RESEARCH

3.1	Overview	32
3.2	Research Objective	32
3.3	Analyzing Research Methods	33
3.4	Description of Research Methods	35
	3.4.1 Secondary Data Study	36

3.4.2	Primary Data Study	37
3.5	Limitation of Research Methods	40
3.6	Summary	41

4 PROBLEM IDENTIFICATION

4.1	Overview	42
4.2	Background and Justification	42
4.2.1	Low Tester Utilization	43
4.2.2	Drive for Flexible Manufacturing	44
4.2.3	Driving Cost Competitive Advantage	45
4.3	Case Study Company	46
4.3.1	Background	47
4.3.2	KMCO	47
4.4	Product Background	48
4.5	Process Background	50
4.6	Equipment Background	52
4.7	Changeover Process Historical Study	54
4.8	Changeover Process Flow in Detail	55
4.9	Problems and Gaps Identification	85
4.9.1	Pre Changeover Activities	87
4.9.2	Preliminary Soft Setups	88
4.9.3	Hardware Part Setups	90
4.9.4	TIU Replacement	99
4.9.5	PnP Teaching Process	100
4.9.6	Dry Cycling Validation	102
4.9.7	TP Download Phase	105
4.9.8	Standard Unit Validation	106
4.9.9	Wrap Up Activities	107
4.10	Summary	109

5 PROPOSED FRAMEWORK

5.1	Overview	110
5.2	Strategy and Execution for Counter Measures	110
5.3	Process Flow Optimization	113
	5.3.1 Upfront Setup Improvement Proposals	116
	5.3.2 TP Download Improvement Proposals	122
	5.3.3 Validation/Calibration Improvement Proposals	125
	5.3.4 Post Setup Activities Alignment Proposals	127
5.4	Optimizing Hardware Setups phase	130
	5.4.1 Proposals to Identify Fungible Parts	132
	5.4.2 Proposals to Identify Non Fungible Parts	132
	5.4.2.1 Non Fungible Parts With Multi Function	132
	5.4.2.2 Non Fungible Parts With Hardware Redesign	133
5.5	Human Dynamic and Procurement Improvement Proposal	135
5.6	Summary	136

6 RESULT AND DISCUSSION

6.1	Overview	137
6.2	Implementation of Pre Setup phase	137
6.3	Improving of TP Download phase	146
6.4	Improving of Hardware Setup phase	149
	6.4.1 Identified ‘fungible’ parts	149
	6.4.2 Identified ‘non fungible’ parts	153
	6.4.3 Redesigning hardware parts	155
	6.4.3.1 Nest redesign	155
	6.4.3.2 One turn screw design	162
6.5	Improvement of PnP teaching phase	171
6.6	Improvement of mechanical unit validation	176
6.7	Improvement of standard unit validation	182
6.8	Elimination of wrap up phase	188
6.9	The new optimized test handler changeover process	189

6.10	Return of Investment (ROI) analysis	191
6.10.1	Capital and cost savings	192
6.10.2	Total utilization indicator improvement	194
6.10.3	Learner and Efficient Training	196
6.11	Critical Appraisal	197
6.12	Future Recommendation / Studies	198
6.13	Summary	199
7	CONCLUSION	200
	REFERENCES	201

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	The seven deadly waste in Lean context	6
3.1	Categories of observations	39
4.1	Physical attributes comparison	50
4.2	Physical attributes comparison to NPI	51
4.3	Hardware parts involve in the changeover	64
4.4	Summary of the changeover process	86
4.5	Problems identified at the pre changeover phase	88
4.6	Problems identified at the preliminary soft setup	89
4.7	Sequence of the contactor chuck replacement	92
4.8	Problems identified during hardware part changes	98
4.9	Problems identified during the TIU replacement phase	100
4.10	Problems identified during the PnP teaching phase	102
4.11	Problems identified during the dry cycling phase	104
4.12	Problems identified during the TP download phase	105
4.13	Problems identified during the standard unit validation	107
4.14	Problems identified during the wrap up activities phase	108
5.1	The 5 pre requisite items and current practice	117
5.2	The ‘Beforehand Cushioning’ proposal	118
5.3	The activity dependency table	119
5.4	Technician idle time	126
5.5	‘Merging’ technique on identifying NVA activities	127
5.6	The current hardware setup phase	131
5.7	Technician headcount per shift	136

6.1	Pre setup improvement result	138
6.2	The new 'End Lot' process sequence	141
6.3	The TP Download improvement result	146
6.4	The identified 'fungible' hardware parts	151
6.5	The identified non 'fungible' hardware parts	153
6.6	The steps in changing the 'nest' size	158
6.7	The actual changeover steps with new 'nest' design	160
6.8	The functionality of the one turn screw	164
6.9	The result of the hardware setup proposals	165
6.10	The time study result of new improved hardware setup	167
6.11	The improvement result of PnP teaching phase	172
6.12	The result of dry cycling phase proposals	177
6.13	The result of the standard unit validation proposals	183
6.14	The result of the wrap up phase elimination	188
6.15	Time study of the overall new optimized changeover process	190
6.16	The actual tool savings by factories for Q3'11	193
6.17	The contribution of TRIZ	197

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	General changeover process	13
2.2	Shingo's original SMED model	16
2.3	Shingo's conceptual stages and techniques	17
2.4	SMED in Lean context	18
2.5	The 40 Inventive Principal	21
2.6	The 4 element model of TRIZ	23
2.7	The contradiction matrix	26
2.8	Tools in TRIZ field	27
3.1	Research Methodology flow	35
4.1	Breakdown of tester utilization	43
4.2	The corporate utilization goal	43
4.3	Example of demand trend	44
4.4	Cost breakdown of Nebula	45
4.5	Inventory impact analysis	46
4.6	Intel Kulim's topography	47
4.7	KMCO's Factory View	48
4.8	Nebula and Nexus sample units	49
4.9	Product roadmap illustration	50
4.10	The process flow	52
4.11	The M4542AD Dynamic Handler	53
4.12	Test module setup	53
4.13	Time trend of conversion from Q2'10 to Q4'10	54
4.14	The generic changeover flow	56

4.15	Generic activities in pre changeover phase	57
4.16	Generic activities in preliminary soft setups	59
4.17	The change of AEPT state	59
4.18	The change of 'sticky' tag indicators	60
4.19	The 'Andon' light	60
4.20	The use of barricades	61
4.21	Reset temperature in the GUI	61
4.22	Manual turn off by pressing 'TEMP' button	62
4.23	Example of change kit box with hardware parts	62
4.24	Complete tool sets	63
4.25	Example of a TIU	67
4.26	Generic flow of TIU replacement phase	68
4.27	Rear of the handler	69
4.28	The 'Clamper' button	69
4.29	The position wheels to move the TIU and test head	70
4.30	Docked TIU on test head	71
4.31	Generic flow of PnP teaching phase	72
4.32	The command menu	73
4.33	Starting the teach sequence	74
4.34	Completing the teaching sequence	75
4.35	Existing the PnP teaching phase	76
4.36	Generic flow of dry cycling phase	77
4.37	Generic flow of TP download phase	79
4.38	Change of CTSC environment	80
4.39	TP download status	81
4.40	Choosing STD1 summary	81
4.41	Generic flow of standard unit validation	83
4.42	Generic flow of wrap up activities	84
4.43	Time study of pre changeover activities	87
4.44	Time study of preliminary soft setups	89
4.45	Time study of hardware part changes	91
4.46	Time study of TIU change phase	99
4.47	Time study of PnP teaching phase	101

4.48	Time study of dry cycling phase	103
4.49	Time study of TP download phase	105
4.50	Time study of standard unit validation	106
4.51	Time study of wrap up activities	108
5.1	The changeover duration factors	111
5.2	The generic proposal model	111
5.3	Extraction of proposal techniques	112
5.4	The generic 'non optimized' changeover flow	113
5.5	The 'serial' flow of activities	114
5.6	Illustration of 'segmented' of TIU phase	120
5.7	The changeover process flow with upfront setup proposals	122
5.8	Segmented TP download phase	123
5.9	The changeover process flow with TP download improvement proposals	124
5.10	The new aligned post setup phase	129
5.11	The changeover process flow with wrap up phase elimination proposal	130
5.12	Current contactor chuck setup	134
5.13	Current 'nest' design	134
5.14	X- pitch blocks	135
5.15	The current screw design	135
6.1	The new pre setup activity flow	142
6.2	Illustration of pre setup phase development	143
6.3	Actual time study of new pre setup phase	144
6.4	Illustration of changeover process change with pre setup phase improvement	145
6.5	TP Download activity breakdown	148
6.6	Illustration of changeover process change with TP download phase improvement	148
6.7	The transfer pick up assembly	150
6.8	The Nebula and Nexus tray difference	150
6.9	The new 'nest' design	157
6.10	Old versus new 'nest' design comparison	157

6.11	New chuck (L) and old chuck (R) comparison	158
6.12	The current X pitch block and screw design	163
6.13	The X pitch block with new screw design	163
6.14	Illustration of hardware setup executed as parallel activity	170
6.15	Illustration of changeover process change with optimized hardware setup	171
6.16	Actual time study of the improved PnP teaching phase	174
6.17	Illustration of PnP teaching phase with activity breakdown	175
6.18	Illustration of the changeover process change with improved PnP teaching phase	175
6.19	The improved dry cycling activity flow	180
6.20	Illustration of the improved dry cycling phase buildup	180
6.21	Actual time study of the improvised dry cycling phase	181
6.22	Illustration of changeover process change with improved dry cycling phase	182
6.23	Activity flow of the improvised standard unit validation phase	186
6.24	Actual time study of the improved validation phase	186
6.25	Illustration of the changeover process change with improvised standard unit validation phase	187
6.26	The new flow of post changeover activities replacing wrap up phase	189
6.27	The new optimized changeover flow	191
6.28	The capital purchase ROI analysis	193
6.29	The cost breakdown analysis (post improvement)	194
6.30	The post improvement utilization analysis	195
6.31	The post improvement technician idling time reduction	196

LIST OF ABBREVIATIONS

ABBREVIATIONS	FULL NAME
AEPT	Automated Equipment Performance Tracking
ATE	Assembly Test Equipment
GU	Goal Utilization
HMLV	High Mix Low Volume
MA	Machine Availability
NA	Not Available
NVA	Non Value Added
PM	Preventive Maintenance
SDT	Schedule Downtime
SPEC	Specifications
SEMI E10	Semiconductor Equipment and Materials International (E10 is spec)
SMED	Single Minute Exchange of Die
TIU	Test Interface Unit
TP	Test Program
TRIZ	Theory of Inventive Problem Solving
USDT	Unscheduled Downtime
VA	Value Added

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter describes a high-level overview of this project. This includes the background of the project, problem statement, objective, scopes and the lastly significance of this project.

1.2 Background of Project

The ever-growing technological envelope and the shrinking of product life cycle have ultimately changed the overall face of today's global economy where trends are more volatile and impulsive with end-customers are more vivid in their choices and selection of products. The 'ripple' of these effects has strongly influenced in the semiconductor industries especially manufactures supporting High Mix Low Volume (HMLV) products. It is well noted that the number of transistors that can be placed inexpensively on an integrated circuit has doubled approximately every two years (Gordon Moore, 1965) which precisely describes a driving force of technological and social change in the late 20th and early 21st centuries and the trend has continued for more than half a century and is not expected to stop until 2015 or later. This has directly impacted the once flamboyant semiconductor industries which

are now facing competitive pressures to meet the ever-changing demand from end customer and at the same time the challenge in reducing the overall operation cost.

Some 3 years ago, when Intel's Kulim Microprocessor and Chipset Operations (KMCO) mega-factory was erected as the biggest offshore facilities (was then taken over by the mega factory in Vietnam in 2nd Quarter 2010) and ramped-up aggressively for HMLV manufacturing (include assembly and testing), there were 2 main mounting challenges for the factory was;

- i. To make a breakthrough in the factory process cycle time (time taken to manufacture a product from start of assembly to finish product ship out)
- ii. To demonstrate a low cost competitive advantage especially when compared against Internal competitors (other Intel factories i.e. Penang, China, Costa Rica and US) and external competitors whom are mostly EMS or other sub-contracted factories

The above 2 challenges are linked together by one similar gating issue which is the conservative or the traditional manufacturing flow which focuses on batch-based production that in return produce large inventory build-ups, high storage cost and overall lower equipment utilization. This manufacturing method opposes exactly the concept of Lean Manufacturing which dictates on identifying and eliminating those waste or Non Value Added (NVA) activities in accordance to achieve optimum performance. Lean advocates for continuous flow and manufacturing flexibility of readily adapting to the market shifts (Anthony Inman, 2010). The ability and competency to be flexible is much easier to be said than done as the complexity to design such facility could be both costly and sophisticated especially on long term sustaining.

This project will fully focus on the case study of reducing the changeover time for an Automated Testing Equipment (ATE) called the 'Extreme Test Handler' in a semiconductor industry by integrating 2 well known problem solving

methodologies; the Single Minute Exchange of Die (SMED) techniques together with the Theory of Inventive Problem Solving (TRIZ) principals.

1.3 Problem Statement and Justification

Today, the non flexible factory environment practices batch build of products and equipment dedication policy at the Test operation area due the long hours of non-optimized changeover process for the Test Handler which in result causes low equipment utilization, high inventory accumulation, higher cost per unit and the rising cost to purchase new capital equipments.

1.4 Objective

The objective of the project is to reduce the changeover duration for a test handler from a current 4.0 hours to 0.5 hours by integrating SMED techniques and TRIZ principals.

1.5 Scopes

The scopes of this project will cover as below:

- i. Only techniques from SMED and TRIZ will be used. All the TRIZ are based only from the 'Principal' tools
- ii. The study is limited only to the chipset products codenamed 'Nebula Peak' and 'Nexus Peak'
- iii. The focus area is the Test operation of the company where the focused equipment M4542AD Dynamic Test Handler (Extreme Handler)

1.6 Significance of Study

The highlights of this project are as below:

- i. Changeovers or conversion for test equipments such as the Test Handlers are rarely studied or practiced upon compared to other assembly equipments such press, lathe or even conveyor based equipments. This could be due to fact that these types of test equipments are only commonly found at high end semiconductor industries with structural and functional die testing capabilities. Also to note is that this type of equipment are more complex and sophisticated technically to change or redesign.
- ii. This project explores the opportunity to apply the SMED techniques to perform changeover for the Test Handler and further enhance the shortcoming of the prior techniques by integrating them with TRIZ principals.

1.7 Thesis Structure

This thesis consists of 7 chapters. Chapter 1 is the introduction of the project with background, problem statements, objective, scopes and the significance of the study. Chapter 2 presents the literature review on Lean manufacturing, rapid changeover, Single Minute Exchange of Die (SMED) and Theory of Inventive Problem Solving (TRIZ) which also consist the critical analysis of each techniques. Chapter 3 is basically the detail of the methodologies used throughout the project. Chapter 4 focuses on the problem identification in the case study where both qualitative and quantitative data collected are presented. Chapter 5 shows the counter measure proposals with respect to the SMED and TRIZ techniques. Chapter 6 is where the end results are presented together critical appraisals and future study recommendations. Chapter 7 is the conclusion and summary of this project.

REFERENCES

- Anderton, J. (2009). Quick Changes. *Canadian Plastic*. January/February 2009, 29-30.
- Angeles, Rolly S. (2009). *World Class Maintenance Management – The 12 Disciplines*. Central Books Supply Inc.
- Association for Manufacturing Excellence (2009). *Sustaining Lean: Case Studies in Transforming Culture*. New York: Productivity Press.
- Farlow, D. (2005). Efficient Line Changeover. *SMT magazine*, March 2005, 44-45
- Fey, V., and Rivin, E (2005). *Innovation on Demand: New Product Development using TRIZ*. Cambridge University Press.
- Karlsson, C., and Ahlstrom, P.(1996). Assessing changes towards lean production, *International Journal of Operations & Production management*. 16 (2), 24-41.
- Kearney, W. (1997). A proven receipt for success: the seven elements of work class manufacturing, *National Productivity Review*. 16, 67-76.
- Lev, S. (2009). *Introduction to TRIZ*. Altshuller Institute Online.
- Levinson, W., & Rerick, R. (2002). *Lean Enterprise: A Synergistic Approach to Minimizing Waste*. Milwaukee, WI: ASQ Quality Press
- Liker, J.K, and Meier, D (2006). *The Toyota Way Fieldwork: A Practical Guide for Implementing Toyota's 4Ps*. United States: The McGraw- Hill Companies.

Lotter B., and Wiendahl H.P.(2009). *Changeable and Configurable Assembly systems*. Springer.

McIntosh, R.I., Culley, S.J., Mileham A.R., and Owen, G.W. (2000). Critical Evaluation of Shingo's SMED Methodology. *International Journal of Production Research*. 38(11), 2377-2395. Taylor and Francis Ltd.

McIntosh, R.I., Culley, S.J., Mileham A.R., and Owen, G.W.(2001). Changeover improvement a maintenance perspective. *International Journal of Production Economics*. 73(2), 153 – 168. Taylor and Francis Ltd.

Mann, D (2001). *TRIZ: The Theory of Inventive Problem Solving*. 10(2), 123-125. Blackwell Publishing Ltd.

Martin G. M. (2005). What is TRIZ? From Conceptual Basics to a Framework of Research. *Creativity and Innovation Management*, 14, 3-13.

Moxham, C., and Greatbanks, R. (2001). Prerequisites for the implementation of the SMED methodology: *A study in a textile processing environment*. *IJQRM*. 18 (4), 404-414. Taylor and Francis Ltd.

Nakajima, S. (1988). *Introduction to TPM*. Cambridge , MA : Productivity Press.

Orloff. M (2003). *Inventive Thinking Through TRIZ: A Practical Introduction*. Berlin: Springer.

Reik, M.P., and McIntosh, R.I. (2006). Formal Design for Changeover Methodology. *A Case Study*. Proc. IMechE, Part B. 220(528),1237-1247

Ross & Associates Environmental Consulting, Ltd. (2003). *Lean Manufacturing and the Environment: Research on Advanced Manufacturing Systems and the Environment and Recommendations for Leveraging Better Environmental Performance*. United States: Environmental Protection Agency.

- Santos, J., Wysk, A.R., Torres, M.J. (2006). *Improving production with lean thinking*. New Jersey: John Wiley & Sons, Inc.
- Shingo, S. (1984). *A Revolution in Manufacturing: The SMED system*. Cambridge, MA : Productivity Press.
- Simon, L., and Vladamir, P (2009). *TRIZ Body of Knowledge*. International TRIZ Association (MA TRIZ), Alshuller Institute, 1-9.
- Sousa R.M., and Lima R.M (2009). *An Industrial Application of Resource Constrained Scheduling for Quick Changeover*. Proc. IEEM, 189-193.
- Taylor, B.W. (2006). *Introduction to Management Science*. (9th ed.). Virginia: Prentice Hall.
- Van, J. V. (2001). Transport Developments Support Fast Changeover In High Volume SMT production. *SMT magazine*, May 2004, 66-69.
- Van Goubergen, D., and Landeghem, H.(2002). Rules for Intergrating fast changeover capabilities into the new equipment design. *Flexible Manufacturing*. Elsevier Science Ltd.
- Vardeman, S. B.(2010). The Impact of Dr. Shingo on Modern Manufacturing Practices. *IE 361*. Utah State University.
- Whitney D.E., (2004). *Mechanical assemblies – their design, manufacture and role in product development*. Oxford University Press.
- Womack, P.J., Jones, T.D., Roos, D. (1990). *The Machine that Changed the World: The Story of Lean Production*. New York: Harper Perennial.
- Womack, P.J., Jones, T.D. (2003). *Lean Thinking*. New York: Free Press.
- Yyes, D.G (2006). SMED reduces changeover time : A case study in a

food industry. *Food Engineering and Ingredients*, November 2006, 32-34.

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