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Product Complexity and Mode Choice in Global Product Development

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Abstract:

Despite the growth in the practice of global product development, little work has been done to understand factors that influence mode choice in global product development. Our research fills this gap in the literature by empirically investigating variables that drive firms to either globally outsource, globally partner or develop modules themselves in a foreign country. We assume a product-centric view, and combine the transaction cost theory and the resource based view of the firm to explain mode choices based on the analysis of electromechanical products developed across Asia, Europe, the Middle East, and South America for (or by) American firms. Though we focus on complexity, we address product content specificity, product strategic importance and designer's technological capability as well. We find significant relationships between the type of global product development and the product characteristics. However, the significance of the relationship between complexity and the mode varies by region when we divide the world into emerging countries and mature countries. While the relationship is significant in the emerging countries, it is not significant in mature countries. These findings have implications for

decision making in systematically assigning modes of development to different products being developed globally.

Key Words: global product development, global outsourcing, product complexity, make or buy

1 INTRODUCTION

Today's complex products involve such rapidly changing technologies that no large parent firm can effectively develop all products in-house at a single location (Fine & Whitney, 1996; p. 101). At the same time, the world is increasingly connected (Friedman, 2005) and foreign economies are growing (Fingar, 2008). As a result, many leading American firms are actively engaged in globally distributed product development. These companies range from leading industrial equipment firms such as Caterpillar and GE Energy, through medical instruments firms such as Perkin Elmer to electronics firms such as Cisco and Flextronics. They are engaging countries as varied as China, India, Sweden, Germany, Brazil and Israel in their product development efforts.

Since research in global product development (GPD) is in its nascent stages, it is not clear what modes of GPD are best suited for developing the different types of product modules. Thus once a product system, e.g. the elevator system, is broken down into modules such as the entrances, machines, controls, drives, etc, there is uncertainty about how product development leaders can best choose the appropriate mode of GPD for each module. It is plausible that module characteristics such as complexity might play a key role in this critical decision. Thus we intend to combine transaction cost theory of the firm and resource based view of the firm to investigate how module complexity influences the mode of global product development.

Insights into how complexity influences the GPD mode decisions provide several benefits to the academic understanding of globally distributed product development and to practitioners alike. From an academic point of view, this paper builds on the make or buy literature in three distinct ways: Firstly, we focus on product development (vs. manufacturing), secondly we emphasize the global aspect of global product development, and thirdly we include global partnership as a third option to the dichotomous make or buy. In the course of doing the research, we also empirically assess the definition of complexity since there is no consensus in product development literature on the definition of complexity at the module level.

From a practitioner's point of view, knowing when to globally develop modules in-house, integrate suppliers, or integrate partners is seen as significantly responsible for the success of the Japanese automobile industry (Clark & Fujimoto, 1991). More recently, Mishra and Sinha (2008) have argued that global product development outperforms local product development as uncertainty increases; thus using the right mode of globalization increases success for the right products. Global partnering or global outsourcing on the appropriate modules also allows the firm to focus on core tasks (Prahalad & Hammel, 1990; Zhao & Calantone, 2003). Finally, and using Cummins as an example, Venkatesan (1992) argues that such a skill is necessary for survival in the engineering of complex products.

The rest of this paper is structured such that section 2 covers related literature, while section 3 addresses research methods. Section 4 describes the multinomial logistics analysis for testing the hypotheses and Section 5 covers the hypotheses tests results. In Section 6 we summarize our findings, and in Section 7, we highlight our contributions to the literature.

2 REVIEW OF RELATED LITERATURE

Global Product Development or Globally distributed Product Development (GPD) is defined as a "single, coordinated, product development operation that includes distributed teams in more than one country utilizing a fully digital and connected collaborative product development process"(Eppinger & Chitkara, 2006, p. 23). Companies are generally practicing two forms of global product development namely module-specific and phase-specific global product development. In module-specific GPD, an entire module is developed outside the program home-country, and in phase-specific GPD, phases of the development process are done outside the program home-country though the design ownership remains in the program home-country. The focus of this paper is on module-specific global product development.

2.1 Modes of Global Product Development

Since hosts engaged by the parent firm in a global product development effort are involved to differing degrees, we define three modes of global product development; captive offshore, global outsource, and global partnership. In captive offshoring, the parent firm owns the product development resources in the foreign country (Eppinger & Chitkara, 2006; p. 26). In global outsourcing, the product development is done in a foreign country by separate "unaffiliated suppliers or outside engineering firms" (Cusumano & Nobeoka, 1990; p. 29). Finally, global partnerships are based on long term relationships, ownership stakes, joint ventures or strategic alliances (Cusumano & Nobeoka, 1990; Dyer, 2000) in product development.

2.2 Factors Influencing the Mode Choice in Global Product Development

Make or buy research is grounded in the transaction cost theory of the firm (Coase, 1937; Williamson, 1981) and the resource based view of the firm (Penrose, 1959; Wernerfelt, 1995). We conjecture that these theories might apply to global product development as well; hence we review key factors covered in both schools of thought (see Langlois & Robertson, 1989; Williamson, 1999), and filter for factors applicable to global product development during the early steps of our research before running statistical tests.

Complexity: There are several definitions of product complexity in product development (Kim & Wilemon, 2003). Many of these definitions are routed in Simon (1962, 1998) who defines a complex system as one made of many parts that have many interactions. For instance, Murmann (1994) defines complexity as the number of parts in a product. Griffin (1997) defines complexity as "the number of functions of a product" (p. 24), while Novak and Eppinger (2001) define product complexity as the number of parts to be produced, parts coupling and the degree of product novelty (p. 189). Given the disparity in the definitions of complexity, we utilize the early steps of our research process to empirically assess the definition of complexity in global product development.

Using government contracts in the aerospace industry, Masten (1984) argues that complexity increases the chances of internally sourcing products. Unfortunately, Masten (1984) does not explicitly define complexity and uses complexity as a surrogate for uncertainty. Likewise, Anne (2007) uses complexity as a surrogate for performances uncertainty. However, she argues that complexity does not influence the make or buy decision. To the contrary, Novak and Eppinger (2001) provide a more precise definition of complexity and argue that producers tend to manufacture complex products in-house based on their study of the automobile industry.

Product Content Specificity: We define product content specificity as the uniqueness of a product. We operationalize this specificity on a 1 through 5 scale, 1 corresponding to 1-10% of the parts off-the-shelf, 11-20 corresponding to 2 etc

As Montverde and Teece (1982) find in the automobile industry, Pisano (1990) finds in R&D in the biotechnology industry, and Masten (1984) finds in the aerospace industry, an increase in production assets specificity increases the odds of in-house production. Several studies with similar conclusions are summarized in a review by Klein (2004). However, Lyons (1995) adds a layer of complexity to the analysis by investigating the moderating effect of economies of scale and scope on the relationship between asset specificity and the make or buy decision. He finds that economies of scale and scope are only significant in the make or buy decision in the absence of asset specificity.

Capability: The factors influencing the make-or-buy decision reviewed above are rooted in the transaction cost theory of the firm. However, transaction costs and capabilities are fundamentally intertwined since the existence of transactions imply heterogeneity in productive capabilities (Conner & Prahalad, 1996; Jacobides & Winter, 2005). Thus firms might choose to develop products in-house in order to preserve capability (Espino-Rodriguez & Padron-Robaina, 2006; Prahalad & Hammel, 1990; Teece *et al.*, 1997) or develop products through one of the external means in order to access capability (Ulrich & Ellison, 2005). In a nutshell, capability can drive a firm to source production internally or externally.

Importance to Strategy: Importance to strategy is another factor which influences the make or buy decision (Manders & Brenner, 1995). Some modules are strategically "indispensable to the company's competitive positioning" and so they are produced in-house (Venkatesan, 1992; p. 101). Some are strategically important but technologically challenging. For these, firms partner globally as a way of reducing risk associated with developing the modules (McIvor *et al.*, 1997). The strategic importance is largely driven by the product differentiation in the market place, (Welch & Nayak, 1992) which is in-turn tied to the core competence of the firm (Leonard-Barton, 1992; Prahalad & Hammel, 1990).

Other Important Factors: There are several other factors that might drive firms towards different modes of GPD. For instance, outsourcing might help firms minimize financial investments (Tayles & Drury, 2001), vary supply to match demand variability (Tripathy &

Eppinger, 2007), control product transaction uncertainty (Levy, 1985; Walker & Weber, 1984; Williamson, 1975) or take advantage of external economies of scale (Cachon & Harker, 2002). Firms might have historical patterns driving them one way or the other (Nelson & Winter, 1982), or they might be influenced by their national culture (Belderbos, 2003; McLaren, 2000). The list is potentially endless. However, we believe the factors reviewed above are the most important to global product development.

Room for Contribution to the Literature: As mentioned above, global product development research is nascent, and the factors reviewed above are drawn from make or buy research in manufacturing. Thus, we firstly contribute by investigating whether the same factors are important in product development. Secondly, references to globalization in the literature are not common. Thus we contribute by focusing on the globalization of product development. Thirdly, there is little consensus on the definition of complexity at the module level. Hence empirically assessing the definition of complexity creates another opportunity for contribution. Finally, the make or buy choice reviewed in the literature is largely binary. We observed a third mode of GPD in the field; hence we add global partnerships to the make or buy choice.

3 Research Methodology and Data Gathering

We use two phases in our research methodology. The first phase utilizes grounded theory to define complexity and generate empirically valid hypotheses (Eisenhardt, 1989; Glaser & Strauss, 1967; Stebbins, 2001). The second phase allows us to test the hypotheses quantitatively (Yin, 2002).

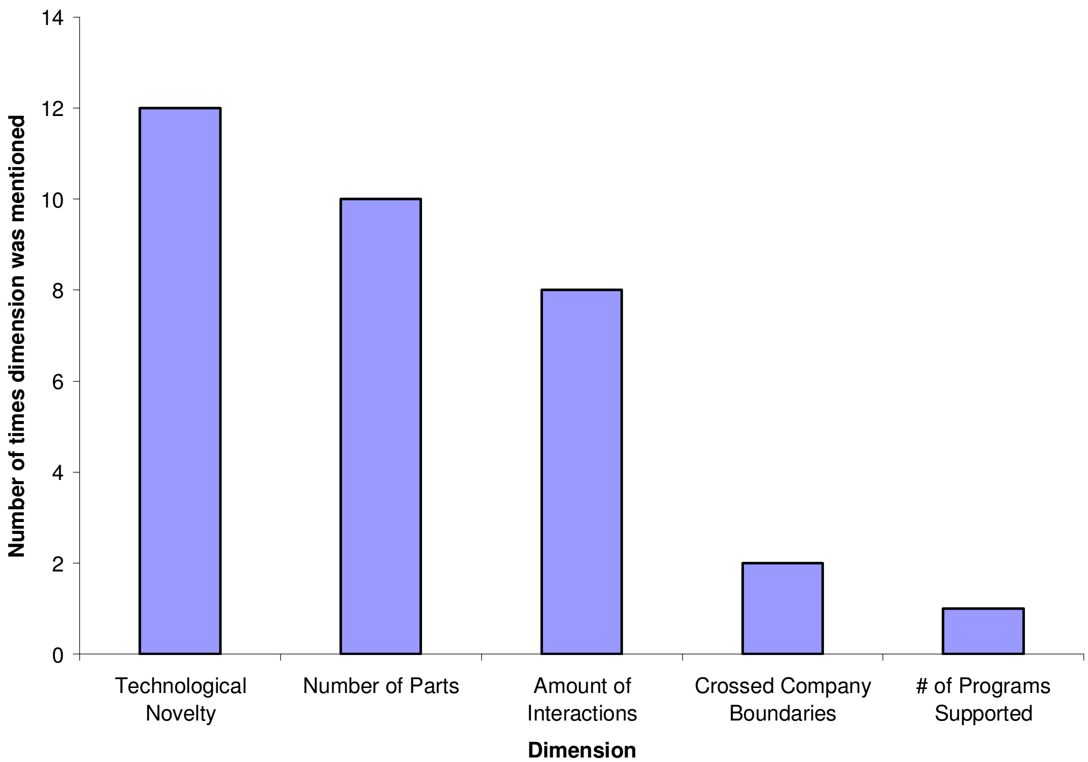
During the first phase, we quota sampled executives developing medical, industrial and electronics product systems. The first cases were selected from a Fortune 10 company where the lead author spent 500 hours working as a global product development engineer. In the spirit of quota sampling, the rest of the 80 interviewees were chief technology officers, directors and vice presidents of engineering selected from 17 other companies. We interviewed them over a period of 15 months.

The data collection process began with open-ended interviews about factors that influence mode choice in global product development and the definition of product complexity in global product development. Each interview was done and recorded in person, and lasted from 30 to 180 minutes depending on the seniority of the interviewee and stage in the research process. The average interview lasted for 60 minutes.

Most of the product development executives were located in the US and a few were located in Europe and Asia though they all worked for large American companies. By focusing on large American companies we controlled for possible firm size and national culture influencing the modes of global product development.

From the interviews, we recorded statements such as "We keep interfaces and customer-facing components in-house," and "complex activities tend to be kept in-house." We coded these two as indicating that 'complexity' and 'strategic importance' are important factors in making mode choice decisions in global product development respectively. Overall, we found that product complexity, designer's technological capability, importance to strategy and product content specificity are important in making GPD mode decisions. From these four, we are primarily interested in product complexity, which we define as a combination of technological novelty, number of parts and amount of interactions based on results tallied in Figure 1. This definition is an extension on Simon's (1962, 1998) definition of complexity and similar to Klibanoff & Novak (2003) and Novak & Eppinger (2001) definitions of complexity.

Figure 1: Tally of the Number of Times a Dimension was Mentioned as Important in Module Complexity



Given the literature reviewed above, we hypothesize the following:

H1: Worldwide, high module complexity increases the likelihood of product development through the captive offshore mode relative to the global outsource mode.

H2: Worldwide, high module complexity increases the likelihood of product development through the global partnership mode relative to the global outsource mode

H3: Worldwide, high module complexity increases the likelihood of product development through the captive offshore mode relative to the global partnership mode.

3.1 Phase II: Hypothesis Testing Methods

Case selection process: The population consists of tier 1 electromechanical modules i.e. subsystems at the first level of decomposition from the entire product system, developed by large American firms outside their program home-country. From this entire population, we used quota sampling (Campbell & Stanley, 1967; Yin, 2002) to sample a diverse set of modules. Beyond the first company, we limited each company to at most 12 modules, and the yield rate was about 6 modules per company.

Data collection processes: We gathered module level data using a data template in which rows represented the modules and columns represented characteristics of the module such as technological novelty, module specificity, number of parts etc. In order to enhance data validity, we clarified our requirements by taking each interviewee through a single row i.e. helped her understand needed data for one module so that she could provide data for the rest. This allowed the executive to ask questions and get clarification on any of the variables represented by the columns. After explaining all variables in detail, we gave each executive a week to complete the rest of the data template. In addition to the template, we gave her a reference document which explained each data column. All executives returned the data template within a couple of days. All in all, we obtained 156 modules. From the 156 modules, we could not use 38 modules. Of the 38 modules, 23 were missing some data, and the remaining 15 were decomposed beyond tier 1. Thus for each of the remaining 118 modules, we gathered data as exemplified by ultra wide band transceiver in Table 1. We obtained raw values from the executives and assigned numerical values as shown in the table for statistical analysis.

We measured strategic importance and designer's technological capability using a three-point scale, and product content specificity as an inverse of the number of modules parts off-the-shelf. Details on how we measured complexity are summarized in the appendix.

Table 1: Ultra Wide Band Transceiver Exemplifying Data Gathered About Each Model

Module Characteristic	Raw Value	Coded Value
Module name	Ultra Wide Band Transceiver	
GPD mode	Global Outsource	3
Number of parts	3	1
Technological novelty	New to the world	5
Interactions	We actively coordinated them, we had frequent meetin	4
Specificity	0%-10%	5
Designer's Capability	Unique	3
Importance to strategy	It's critical to our strategy	3
Development Location	Israel	
Monthly Labor Cost	$2111 (average of 2003, 2004 and 2005)	

4 Analysis

4.1 Multinomial Logistic Regression

Equation 1: Hypotheses in the Form of a Multinomial Logistic Model

$$Mode = \beta_1(Product\ Complexity) + \beta_2(Product\ Specificicty) + \beta_3(Strategic\ Importance) + \beta_4(Designer's\ Capability)$$

We use the model in Equation 1 to test our hypotheses. The dependent variable has three possible values i.e. global partnership, captive offshore, or global outsource; hence we use a multinomial logistic regression model to test the hypotheses (Garson, 2008). For each module, the outcome of the model is a probability of development through any of the three modes of global product development. It is customary to discuss these probabilities in the form of odds ratios. The odds ratio of an event is defined as the quotient of the probability of the event happening (e.g. being captive offshored) and the probability of the event not happening (i.e. being globally outsourced or captive offshored). The odds ratio can be represented as a function of module characteristics as shown in Equation 2 (Albright *et al.*, 2004).

Equation 2: Odds Ratio as a Linear Function of Module Characteristics

$$\frac{\rho_j}{1-\rho_j} = e^{\beta_{j0}+\beta_{j1}x_1+\ldots\beta_{jk}x_k}$$

Where:

- ρ_j = probability of global product development through mode j
- x_i= independent variable e.g. complexity; i = 1, 2…k
- β_{ji} = coefficient of the respective independent variable in mode j; i = 0, 1…k

5 Hypotheses Tests Results

The complexity likelihood ratio test significance is less than 0.05 as shown in Table 2A. Thus there is a statistically significant relationship between the mode of global product development and module complexity.

The complexity odds ratios in Table 2C Model 1 indicate that the odds ratio for module complexity is 261% in favor of captive offshoring, and 506% in favor of development through global partnership relative to global outsourcing. This means that given captive offshoring and development through a global partnership as alternatives to global outsourcing, complex modules are more likely to be captive offshored or developed through a global partnership. Thus hypotheses (H1) and H (2) are supported by the data at a significance level less than 0.01.

However, the difference between development through global partnership and through captive offshoring is not statistically significant though the global partnership is associated with slightly high complexity. Thus hypothesis (H3) is not statistically supported by the data.

We also find that designer's technological capability, importance to strategy, and product content specificity are statistically significant in determining the mode of global product development as shown in Table 2.

Table 2: Worldwide Multinomial Logistics Model Results

Table 2A: Likelihood Ratio Tests P-Values	Model 1
Intercept	0.00
Complexity	0.00
Designer's Technological Capability	0.00
Importance to Strategy	0.00
Content Specificity	0.01
Chi-Square	75.02

Table 2B: Case Processing Summary (N)	Model 1
Global Partnership	20
Captive Offshore	41
Global Outsource	55
Valid	116
Missing	2
Total	118

Table 2C: Model Odds Ratios

	Odds Ratio	Model 1: Captive Offshore[a] vs. Global Outsource	Model 1: Global Partnership[a] vs. Global Outsource	Model 1: Captive Offshore[b] vs. Global Partnership
Complexity	$\exp(\beta_1)$	3.61***	6.06***	0.6
		(12.00)	(14.92)	(1.31)
Designer's Technological Capability	$\exp(\beta_2)$	0.21***	0.43*	0.49*
		(13.17)	(3.61)	(2.68)
Importance to Strategy	$\exp(\beta_3)$	2.71**	0.69	3.91***
		(6.02)	(0.75)	(8.55)
Content Specificity	$\exp(\beta_5)$	1.81***	1.81**	1
		(7.18)	(4.87)	(0.00)

a = reference category is the global outsource b = reference category is the global partnership
Wald statistic for testing null hypothesis that logit is zero are shown (in parentheses)
*$p < 0.1$ **$p < 0.05$ ***$p<0.01$

5.1 Further Analysis: Mature vs. Emerging Countries

The 118 modules in the study are developed in 25 countries. We divided the list of countries into mature and emerging countries based on engineering wages obtained from the International Labor Organization. Table 3A shows the overall likelihood ratio tests of the same model run on two separate data sets, i.e. mature model run using data from modules developed in mature countries, and emerging model run using data from modules developed in emerging countries.

From Table 3A, complexity is not a statistically significant differentiator among the GPD modes in mature regions, but it is statistically significant in emerging regions. We conjecture that this is because firms in mature countries are capable and have sound coordination infrastructure so that any of the three modes can develop complex modules. In emerging regions, we find that captive offshores and global partnerships are associated more complex modules relative to the global outsource mode. This result is in line which the current thinking in the literature.

6 Summary

We investigated the relationship between three modes of global product development, namely: global partnership, captive offshore and global outsource, and product complexity. We find that complex modules are more likely to be captive offshored or developed through partnerships than being globally outsourced when all modules are pooled together. The same relationship holds in emerging regions but not in mature regions where complexity does not differentiate modules based on their mode of development. We also find that product content specificity, strategic importance and designer's technological capability are statistically significant in differentiating modules based on their mode of GPD mode.

7 Contributions

Based on the findings above, we extended the make/buy literature in four key ways:

- We focused our analysis on product development, thus moving beyond manufacturing which had been the staple in the make or buy literature.
- We extended the literature beyond the dichotomous make or buy choices by including the global partnerships mode.
- We added the global aspect of product development by restricting our study to modules developed outside the program home-country.
- We empirically assessed the definition of complexity in global product development because there is no widely used definition of complexity at the module level

Table 3: Mature vs. Emerging Regions: Multinomial Logistic Model Results

Table 3A: Likelihood Ratio Tests

	Mature	Emerging
Intercept	0.00	0.97
Designer's Technological Capability	0.00	0.08
Complexity	0.11	0.00
Importance to Strategy	0.00	0.88
Content Specificity	0.01	0.43
Chi-Square	63.5	25.57

Table 3B: Case Processing Summary (N)

	Mature	Emerging
Global Partnership	12	8
Captive Offshore	31	10
Global Outsource	34	21
Valid	77	39
Missing		2
Total	77	41

Table 3C Models Odds Ratios

		Mature Regions			Emerging Regions		
	Odds Estimated	Captive Offshore[a] vs. Global Outsource	Global Partnership[a] vs. Global Outsource	Captive Offshore[b] vs. Global Partnership	Captive Offshore[a] vs. Global Outsource	Global Partnership[a] vs. Global Outsource	Captive Offshore[b] vs. Global Partnership
Designer's Technological Capability	$\exp(\beta_2)$	0.20***	0.63	0.31*	0.37	0.19	1.910
		(9.05)	(0.68)	(4.12)	(1.53)	(2.64)	(0.48)
Complexity	$\exp(\beta 3)$	1.88	4.17**	0.45	4.11**	10.87***	.380
		(1.11)	(4.06)	(1.27)	(6.09)	(8.91)	(1.73)
Importance to Strategy	$\exp(\beta_4)$	8.04***	0.67	12.04***	1.36	1.04	1.31
		(7.59)	(0.44)	(8.80)	(0.32)	(0.00)	(0.18)
Content Specificity	$\exp(\beta_5)$	2.23**	2.32**	0.96	1.36	1.59	0.86
		(6.04)	(5.00)	(0.01)	(0.81)	(1.15)	(0.15)

a = reference category is the global outsource b = reference category is the global partnership

Wald statistic for testing null hypothesis that logit is zero are shown (in parentheses)

*p < 0.1 **p < 0.05 ***p<0.01

8 Appendix: Measuring Complexity

We defined complexity to be a function of the number of parts, technological novelty and amount of interactions. We asked the respondents to give us the number of parts in the module, and converted the value into a 1 through 5 score (Porter et al., 2006). This conversion allowed us to compare the real number with scale values from other independent variables.

We created a 1 through 5 scale for measuring technological novelty. At the top is “New to the World” which is a (5) on the scale, “New to our Industry Worldwide” which is a (4), “New to My Company Worldwide” which is a (3), “New to my Company Locally” which is a (2), and “Not New at All” which is a (1) on the scale. Other measures such as patents (Griliches, 1990) are not applicable in this case since firms rarely patent discoveries from product development (Makumbe, 2006).

We used a coordination scale to measure the amount of interactions associated with each module. Since there are many reasons for coordination (Allen, 1977) we limited our interests to coordination driven by interfaces in product development. Note that the amount of coordination during the product development process varies, hence the data is biased towards the frequent or more memorable interactions (Reagans et al., 2004; Wasserman & Faust, 1994). The scale is such that “We Completely Integrated them, they had to work on the same contract” is a (5), “We Actively Coordinated them, we had Frequent Meetings” is a (4), “We Actively Coordinated them, we had Infrequent Meetings” is a (3), “We Actively Coordinated them by Copying them on Communications” is a (2), and “We Encouraged Coordination but we did not Actively do Much” is a (1).

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