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***STANFORD  
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# letter from the editors

Dear Reader,

We are delighted to present to you the seventeenth edition of the Stanford Undergraduate Research Journal (SURJ). Since its founding in 2001, SURJ has produced intellectually vibrant collections of outstanding undergraduate research to celebrate students' accomplishments, share their discoveries, and promote an investigative spirit among undergraduates. This edition of SURJ, like its predecessors, reflects our hardworking staff's commitment to scientific communication and showcases nine exceptional undergraduate submissions from Stanford and other universities around the world.

For our part, SURJ proudly strives to communicate important and relevant research findings in an accessible manner to the general public. In this edition, we invite you to examine the impact of carbon tax policies in context of the modern political climate with Mary Zhu ('17), explore Socialist Realism through Russian literature set during the Soviet period with Tiffany Zhu ('21), delve into progress of gender equality in China via the 1931 Jiangxi Chinese Soviet Republic Marriage Regulation with Lillian Lin ('18), and consider a cost-competitive biodiesel fuel synthesized from fermented rice by-products with Taryn Imamura ('20).

This year, we have the dubious honor of publishing during one of the most politically controversial years in U.S. history. Under the current Trump administration, the position of White House science adviser has remained empty longer than under any other

modern president. In a time of "alternative facts," "fake news," and a political administration outright hostile to scientific inquiry that supports healthier lives, informed government policies, and cleaner environments, we remain more cognizant than ever about the importance of effective science communication and open-access journaling. Each political blow by Trump, Scott Pruitt, and others who have undercut scientific and environmental efforts rallies our generation to stand firmer, fight fiercer, and work harder to give a voice to real facts, not alternative ones. Science clearly is not, and has never been, conducted in a vacuum, as the current political climate heavily illustrates. We hope the pieces chosen for this year's edition of SURJ emphasize how important scientific research is in building a sustainable and healthy future for the coming generations.

Here, we celebrate the research endeavors of our fellow undergraduate community, invite discourse about environmental studies and policy analyses, and support the inquisitive scientific spirit in each and every of our authors, editors, and dear readers. Thank you to ASSU, SAL, and the Stanford undergraduate body for your continued support of SURJ. And, a huge thank you as well to the SURJ staff, especially Michelle Chang ('20) and Eric Zelikman ('20) for contributing to SURJ through multiple roles. On behalf of the 2017-2018 SURJ staff team, thank you for reading this journal. We hope you enjoy the wonderful work that awaits in the pages ahead.

Sincerely,  
Melodyanne Cheng ('18) and  
Ramya Balasingam ('19)  
Editors-in-Chief

# mission

The mission of the Stanford Undergraduate Research Journal is to encourage, recognize, and reward intellectual activity beyond the classroom, while providing a forum for the exchange of research and ideas.

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# Putting the Realism in Socialist Realism: Gorky's *Mother* as a Bridge between Soviet and Chernyshevskian Literary Aesthetics

TIFFANY ZHU, STANFORD UNIVERSITY

The very first formulation of Socialist Realism in the 1934 Congress of Soviet Writers took inspiration from characteristics of earlier novels that were retroactively deemed ideal for emulation. One of these proto-Socialist Realist works, Maxim Gorky's 1906 novel *Mother*, reflects a Marxist twist on a much earlier so-called realist aesthetic proposed by nineteenth-century thinker Nikolay Chernyshevsky. Though Chernyshevsky called his aesthetic realism, it was less focused on verisimilitude than the faithful depiction of social realities and thus ripe for Marxist reinterpretation. *Mother* capitalizes on that depiction of social realities, especially social expectations for women, but it also incorporates critiques of bourgeois values that are explicitly Marxist in nature, making it ideal for official favor in the Soviet Union. Thus as characteristics of *Mother* were retaught to aspiring Soviet writers, and the novel itself was promulgated as part of the Socialist Realist canon, Chernyshevsky's realism left an indirect yet profound imprint on later Soviet Socialist Realist novels and on Socialist Realism in general.

## INTRODUCTION

One of Socialist Realism's many paradoxes is that despite its name, on the surface it hardly resembles realism. Indeed, Rufus W. Mathewson is hard-pressed to find any realist elements in Socialist Realism at all and sees it instead as a "heroic" aesthetic, one better termed "socialist romanticism" since it often glorifies a Communist future and Marxist ideology in lieu of depicting realistic personages [1]. Meanwhile, Katerina Clark diagnoses Socialist Realism with "modal schizophrenia," a paradoxical mixture of epic and realistic qualities, the simultaneous treatment of what is and what ought to be [2]. However, even if Socialist Realism does not resemble what most think of as realism, it draws inspiration from an unexpected shade of realism: that of radical nineteenth-century thinker and writer Nikolay Chernyshevsky. From its outset, Chernyshevsky's realism separated itself from verisimilitude: it prioritized discussing social and political, especially class, realities, over making stylistic elements such as dialogue naturalistic. The influential vision of Socialist Realism that writer Maxim Gorky espoused in his 1934

Writers' Congress address drew on Chernyshevsky's focus on social realities and added that a writer must address these realities using Marxist critiques. Gorky's early novel *Mother*, by retroactively embodying Gorky's conception of Socialist Realism, reflected the influence of Chernyshevsky's realist thought and imparted that influence to later Soviet writing through its status as an exemplary Socialist Realist novel.

## OVERVIEW AND DEFINITION OF SOCIALIST REALISM

Socialist Realism refers broadly to the literary aesthetic the Soviet state promoted and enforced from 1932, when the term was coined, to the Soviet Union's collapse in 1991 [3]. Although the Western consensus sees it as a static oppressive system imposed from the top, the more complex reality is that Socialist Realism underwent many iterations, and even its genesis was not a top-down imposition of form but rather the organic evolution of an ideal that Maxim Gorky and Andrei Zhdanov's renowned 1934 formulations could not pin down [2]. Nevertheless, as a working definition of Socialist Realism, those formulations

suffice to describe the Socialist Realism theorized and practiced in 1930s Soviet Russia.

At the First Congress of Soviet Writers in 1934, Zhdanov famously provided the most concise formulation of Socialist Realism:

In the first place, it means knowing life so as to be able to depict it truthfully in works of art...not simply as "objective reality," but to depict reality in its revolutionary development. In addition to this, the truthfulness and historical concreteness of the artistic portrayal should be combined with the ideological remolding and education of the toiling people in the spirit of socialism [4].

Though Zhdanov emphasized "truthfulness" in artistic and literary depictions of how the working classes lived, he also encouraged artists to layer on an ideological interpretation of ordinary people's living conditions. A Marxist examination of real-life events and conditions, which would teach people to think in a socialist mindset, must supplement historical accuracy and the accurate portrayal of details such as dialogues and settings [4]. This formulation is not original to Zhdanov: it actually restates the definition of Socialist Realism that Maxim Gorky

supplied in bits and pieces starting in 1930, so Zhdanov's conception of Socialist Realism is really a condensed version of Gorky's [5]. At the same conference, Gorky added:

Socialist realism proclaims that life is action, creativity, whose aim is the continual development of man's most valuable individual abilities for his victory over the forces of Nature, for his health and longevity, for the great happiness of living on earth, which he, in conformity with the constant growth of his requirements, wishes to cultivate as a magnificent habitation of a mankind united in one family [6].

According to him, Socialist Realist works extol the collective accomplishments of humankind and glorify man's power to overcome both nature and the bourgeoisie [6].

Gorky's Socialist Realism extended the implications of Zhdanov's formulation to assert that Socialist Realism should actually lay more importance on historical accuracy than realistic, believable details or language. Still at the Writers' Congress, Gorky suggested that exemplary Socialist Realist works did not have to be fiction, noting that journalistic nonfiction like a "history of towns once ruled by independent princes or located on the old borders" related through "sketches and stories" seemed particularly promising [6]. Yet even though he used to fixate on "inexactitudes in language and quotidian details" in the 1910s and early 1920s, Gorky did not comment on the "truthfulness" that Zhdanov implied [5]. After the late 1920s, especially as Stalin consolidated power, Gorky turned his focus to portraying a higher truth, the "truth...we are building" and the new reality that would supposedly take shape soon [5]. He dismissed extreme attention to small details as an "old, rotten, dying" approach to literature and largely overlooked it thereafter, as his and Zhdanov's 1934 definition of Socialist Realism reveals [5].

### CHERNYSHEVSKY'S REALISM AND PARALLELS TO SOCIALIST REALISM

Realism broadly refers to an

aesthetic system prominent in Western Europe and Russia between 1830 and 1890 that reacted against Romanticism's perceived emotional and individualistic excesses and extremely subjective narration [7]. Although realism was never cleanly summarized in a manifesto and possesses numerous national and individual offshoots, some common values include portraying ordinary people (with special attention to the industrial and rural poor) and mundane, day-to-day events, employing objective narration, using natural-sounding dialogue, and maintaining psychological accuracy [8]. Gustave Flaubert, a French realist, noted that "[t]he author in his work must be like God in the universe, everywhere present, but nowhere visible." In other words, the narrator must not obviously impose an ideology

“ Radical realism took the portrayal of the poor that was always part of traditional realism and ascribed to it a social agenda, sacrificing typical realist tenets like natural dialogue.

or layer any interpretation upon events as good or bad, desirable or undesirable, but rather report events and characters detachedly [7]. Generally speaking, the term realism implies mimesis of life, or depicting life as it is—verisimilitude to forms of speech, faithful depictions of socioeconomic situations, and the use of mundane, plausible events to drive fiction.

Although this definition of realism more or less captures the popular conception of realism, it glosses over the intricacies of nineteenth-century Russian realism. Russian realism is itself an umbrella term for numerous aesthetic practices in nineteenth-century Russia that could arguably be construed as realist. Ernest J. Simmons distinguishes between at least six authors' flavors of Russian realism during this time [9]. Meanwhile, the Cambridge History of Russian Literature highlights the work of radical realists whose flavor of realism departs from the realism often attributed

to Tolstoy or Dostoyevsky. These radical realists hailed predominantly from the motley, mixed-background *raznochintsy* (literally "of many ranks") and included many nihilists, among them Nikolay Chernyshevsky [10].

Radical realism took the portrayal of the poor that was always part of traditional realism and ascribed to it a social agenda, sacrificing typical realist tenets like natural dialogue, unbiased narration, and the narrator's self-effacement that Flaubert demanded. Radical Russian realism, particularly Chernyshevsky's, refers less to the accurate reproduction of reality than the use of socioeconomic realities as a springboard for commentary and criticism. More than a faithful portrayal of daily life, the treatment of real, relevant socioeconomic or political situations—

for example, the industrial poor's mistreatment or the systematic oppression of women—as literary inspirations characterizes radical realism. Notably in *What Is To Be Done?*, which focuses on an extraordinarily empowered heroine, Chernyshevsky forewent mundanity altogether in favor of proposing a solution

to the current, relevant problem of women's oppression through the self-enlightenment of Vera Pavlovna, the novel's protagonist. Chernyshevsky himself did not believe in mimetic realism. The aesthetic he articulated in his seminal *Aesthetic Relations of Art to Reality* did emphasize the accurate portrayal of socioeconomic or political realities, but he did not see it as an end in itself. Rather, he saw that accurate portrayal as a foundation for commenting effectively on these realities from a subjective or even ideological standpoint.

This room for the artist to layer on a subjective interpretation of reality proves crucial in distinguishing his approach to realism from others. Art's primary purpose might well be "to reproduce what is of interest to man in real life" [11]. Even so,

The poet or artist cannot cease to be a man and thus he cannot, even if he

wants to, refrain from pronouncing judgment on the phenomena he depicts. This judgment is expressed in his work – this is another purpose of art, which places it among the moral activities of man [11].

Although writers may strive to reproduce social realities in a novel, for example, they cannot help but impose an interpretation on the realities they portray. An author might, for instance, unconsciously focus on one particular social issue, or emphasize aspects of reality that bolster an ideological position, even if he or she tries to remain objective. Furthermore, Chernyshevsky explicitly warned against an interpretation of his aesthetics as advocating for mimetic portrayals of reality. He deemed art that solely mimicked natural dialogue or devoted painstaking attention to mundane details “superfluous”: since the details such art tries to reproduce already exist perfectly in nature, this type of realism represents a “vain effort” [11]. Contrary to what Mathewson asserts, Chernyshevsky did not believe that art should be judged primarily by “the accuracy with which this relatively humble act of reporting” on day-to-day matters “is carried out,” nor did he think that any slight deviation results in “falsification” [1]. He certainly saw value in verisimilitude, but just as integral for him was the lens through which the author filtered realistic events and, by extension, the lens through which the reader would interpret the realities portrayed—in fact, he deemed these interpretative stages an accompanying “moral” aspect of art [11]. This interpretive lens distinguishes Chernyshevsky’s realism from the mimetic realism to which the word realism typically refers. Indeed, James P. Scanlan notes that the term realism itself misleads heavily when used to describe Chernyshevsky’s aesthetics, since it evokes a mimetic idea of “faithfulness to an existing reality” that comprises only part of Chernyshevsky’s idea [12]. Certainly the subject matter of a work must be derived from real-life social problems, but simply by virtue of turning that content into a narrative, every author manipulates the manner in which that subject matter is treated, whether by giving importance to some

issues or strongly implying opinions on them [12]. In fact, the good artist was obliged to explicate life much as scientists explained natural laws [11].

### GORKY'S SOCIALIST REALISM: AN OUTGROWTH OF CHERNYSHEVSKY'S REALISM

Gorky’s conception of Socialist Realism also valued truth so long as it permitted the author to cast an ideological—in his case Marxist-Stalinist—judgment on the reality depicted. At least in theory, Gorky lent some credence to art that depicted life as it is, acknowledging that mimetic works contributed “formal achievements in the art of word imagery” [6]. He was quick to clarify, however, that critical realism, his vision of mimetic realism, was useful “only in order to throw light upon survivals of the past, and wage a struggle for their eradication,” in other words to elucidate historical conditions [6]. As much as one can discern his meaning through ideological rhetoric, he wanted Socialist Realism to build on critical realism’s achievements by incorporating a “socialist individuality” lacking in critical realism [6]. He hoped that by encouraging the “continual development of man’s most valuable individual abilities” to triumph over common adversaries like natural forces, Socialist Realist literature would enlighten its readers to the need to unite and liberate themselves from capitalist oppression [6]. That said, Gorky still expected authors to adhere to some realism in their work, for they remained “‘judges of the world and of people’, and ‘critics of life’” just as in “traditional realistic literature” [6]. Still, he did not enumerate standards for realism, leaving the option open for artists to pursue techniques departing from pure verisimilitude.

Gorky’s flexible vision, which addressed social realities and ventured Marxist interpretations of their solutions,

allowed it to mingle with seemingly contradictory aesthetic principles. Thus it encompasses the apparently antithetical “revolutionary romanticism,” a style in the early 1930s that demanded that writers “‘anticipate the future shape of man’ and ‘heroize,’ ‘monumentalize,’ ‘romanticize,’ or ‘exaggerate’ him” [2]. Under Gorky’s conception of Socialist Realism, writers could express such exaggerations while still claiming to be realist, even if they pulled themselves “away from verisimilitude” in the process [2]. These exaggerations would be part of the interpretive, in this case Marxist, lens an author would layer onto the realities he or she portrayed. Edward J. Brown further testifies to Socialist Realism’s ability to fold in aesthetics even diametrically opposed to mimetic realism when he claims that “symbolist technique” is typical of Gorky’s work [13]. Alleging that this mix of styles

“Gorky’s flexible vision, which addressed social realities and ventured Marxist interpretations of their solutions, allowed it to mingle with seemingly contradictory aesthetic principles.

constitutes “contamination,” he ventures that the eponymous heroine of *Mother*, “by moving in the direction of the Bolsheviks[,] rejects her traditional woman’s lot in the world,” a blatantly progressive stance bordering on romantic individualism. Even if a character like the mother was atypical in her tsarist Russian setting, however, by casting her development as empowering and attributing its success to her socialist agitation, Gorky proposes a solution to the social reality of women’s oppression and the class reality of lower-class suffering.

Clark raises an objection to a core premise of Gorky’s definition of Socialist Realism, that Socialist Realism is a legitimate aesthetic and not just empty shorthand for a Soviet state-approved work. Describing “Soviet Socialist Realism as a canonical doctrine defined by its patristic texts,” Clark



implies that Socialist Realism is devoid of intrinsic qualities—Socialist Realism is hardly more than a term encapsulating salient characteristics of certain pre-1934 works [2]. (“Patristic” here indicates a parallel between so-called Socialist Realist writers and early Christian theologians who later had works written about them.) To be sure, what constituted a Socialist Realist novel was not static or fixed. However, without taking a detour into pure aesthetic philosophy and defining what constitutes a true literary aesthetic, it seems problematic not to acknowledge Socialist Realism’s legitimacy as an aesthetic. Much like modernism or Dadaism, Socialist Realism was more than a descriptive term: it originated a new standard for literature. Even as the 1934 definition based itself on the characteristics of past works, including *Mother* but also other pre-1934 works like Dmitri Furmanov’s *Chapayev* (1923) and Fyodor Gladkov’s *Cement* (1925), it set a precedent for most later Soviet literary works, a standard that was rigorously and infamously enforced. As for the proto-Socialist Realist novels, the novels written before 1934 that the Soviet state later deemed exemplars of Socialist Realism, the 1934 definition certainly summarized their characteristics as well, but it accomplished more than that in establishing a formal aesthetic future artists would be expected to follow.

In fact, if there were one work the 1934 definition described best, it would be *Mother*. Granted, numerous novels made up the Socialist Realist canon, but in addition to being published the earliest, *Mother* was best suited as a blueprint for an ideal Socialist Realist work. *Cement*, for example, suffers from “ambiguity in placing its heroes on the positive/negative spectrum” that prevents the reader from inferring a strict, ideologically pure Marxist interpretation [2]. Meanwhile, though Chapayev convincingly applies a Marxist turn to the biography of a Russian Civil War hero, Furmanov explicitly tried to humanize Chapayev’s protagonist, inserting a “human” element that would distract from Socialist Realism’s ideological emphasis [14]. *Mother*, on the other hand, lacks this individuality, its plot and characterization being designed to glorify socialism in part by commenting on social realities through a socialist lens.

From a Western or non-Marxist viewpoint, this ideological interpretation of reality might be a fault, but from a Marxist viewpoint, it is aesthetic orthodoxy.

### **MOTHER: AN UNCANNY PREDICTOR OF SOCIALIST REALISM**

*Mother* was primarily responsible for spreading Chernyshevsky’s ideas and techniques to later Socialist Realist literature. Not only did it embody the Chernyshevskian qualities of Socialist Realism (despite being written prior to the formulation of Socialist Realism in 1934), it was also officially deemed an exemplar of Socialist Realism, a status that allowed its influence to permeate later Soviet literature. Through this influence, *Mother* transmitted an aesthetic borrowing greatly from Chernyshevsky into later Soviet writing.

Gorky wrote *Mother* during his involvement with the Znanie publishing house, where he was “largely responsible for its orientation towards realistic works with a social tendency, contributing some himself” [7]. In other words, these works would criticize existing social situations [15]. In 1906, he traveled to the United States to raise funds for the Bolshevik Party and wrote *Mother* while there [15]. Later Gorky would repudiate the novel, admitting to Gladkov that *Mother* was “a really bad book” [16]. However, his original intention when writing the novel is easily inferred from an article he wrote in the same year *Mother* was published, “The City of Mammon,” where he castigated Americans’ idolatrous materialism and predicted “a conflagration which will cleanse this country from the dirt of gold,” a thinly veiled metaphor for Communist revolution [17]. Granted, part of his vitriol stemmed from his poor treatment in America after people discovered that the woman traveling with him was not his wife [15]. Still, his primarily class-centric critiques reveal that he believed sincerely in socialism’s ultimate triumph and thus most probably wrote *Mother* with genuine intentions.

In any event, whether Gorky later developed a distaste for *Mother* is largely moot: whatever private comments he made, his novel was still retroactively held up as an exemplar of Socialist

Realism and made its largest mark on Soviet literature through that designation. Clark argues convincingly against the idea that *Mother* influenced other Soviet novels in a chain reaction where one writer read *Mother*, was inspired, wrote a similar novel, and so on [2]. Meanwhile, Brown draws attention to the press and critical commentary that Gorky’s more Symbolist short stories garnered, duly recognizing that Gorky was not just known for *Mother* [13]. The key was that in the Soviet Union at the time the foundations of Socialist Realism were being laid, *Mother* became part of “a core group of novels that are cited with sufficient regularity to be considered a canon” of Socialist Realist literature, that is, widely enough regarded as Socialist Realist that it could be touted as one exemplar among many to aspiring writers [2]. Thus when 1930s Soviet writers underwent training in literary institutes to craft proper Socialist Realist novels, they assimilated the style, characters, and even the overall plot structure, which Clark terms the “master plot,” of canonical works including *Mother* [5]. As a result of the incorporation of its structure and style into writer training, *Mother* laid a foundation for the “Russian revolutionary novel” that “assert[ed] the right of literature to make an independent, unorthodox, free judgement of social and political reality in the name of revolutionary change” [18]. Later novelists, from Aleksandr Fadeyev to Vsevolod Ivanov, Aleksey Tolstoy, and even Pasternak would write novels in a similar vein [18]. One of *Mother*’s exemplary aspects was the positive hero, an archetype it helped pioneer. This indirect influence on the overall literary style of the period, more than direct inspiration of specific authors or works, constitutes *Mother*’s greatest impact on Soviet literature.

*Mother* predicts most of the characteristics of the Socialist Realism Gorky and Zhdanov ventured in 1934: in addition to maintaining historical accuracy, the novel ingrains socialist thinking in his or her readers by interpreting real-life conditions from a Marxist perspective. Of course, part of *Mother*’s task of historical veracity is accomplished simply by taking inspiration from the real-life 1902 May Day demonstration. Gorky based the

novel's primary characters, Pavel Vlasov and his mother Nilovna, on two socialist figures, Pyotr Zalomov and his mother Anna Kirillovna, who organized a May Day demonstration in the town of Sormovo in 1902, and he structured the plot to parallel the 1902 demonstration [18]. Much as the real Anna Kirillovna began taking part in organizing socialist demonstrations after Zalomov's exile, the mother in Gorky's novel distributes socialist pamphlets to further the socialist cause following Pavel's arrest. This real-life inspiration in itself suggests Gorky intended to address the social and political realities surrounding people like Zalomov and his mother, and he indeed did so by fictionalizing the Zalomovs' broader narrative into a more specific yet believable story. For instance, elaborating on the ways Anna Kirillovna persisted in aiding her son "in his political activity" even after his exile, Gorky has his Nilovna up her revolutionary activity following her son's arrest, smuggling revolutionary pamphlets in her dresses to a neighboring town [18]. This interplay between situations taken from real life and fictional specifics aimed at furthering an agenda point to Mother's intent to raise "workers' political awareness and their expression of dissatisfaction" and spread Marxist revolutionary ideals [18].

Furthermore, the text comments heavily on then-current social realities, in particular injustice directed towards the peasants and the oppression of women. Granted, the question of how feminist Gorky and the Socialist Realists might have been is hefty and not the focus of this paper. Still, the character of Sofya demonstrates Gorky at least tried to portray a counterpoint to the traditional expectation for women to be housebound and passive. She also encapsulates several features of a Socialist Realist character: her role addresses the contemporary reality of women's oppression, and her views object to bourgeois frivolity. A devoted socialist, Sofya leads an indubitably active life assuming various identities, smuggling "illegal books," and helping "comrades in exile" or banished political prisoners flee abroad [19]. Moreover, Gorky grants her the pivotal role of giving the mother a stronger reason to help the socialists than just love for Pavel:

he uses Sofya's evocative piano playing as a metaphor for helping the mother relate personally to the revolutionary moment. Much as Nilovna does not quite understand at first what Pavel advocated but later realizes what socialism is, the incomprehensible "ringing chaos" of Sofya's music becomes "music, distinguished from the tumultuous chaos of sound" [19]. The music subsequently leads the mother to remember "wrongs long forgotten," in particular an incident in which her husband beat her and threw her and Pavel from the house [19]. These recollections, combined with the "perplexed hopes" that the music grants her with its "fresh and firm embrace," lead Nilovna to a new socialist consciousness that solidifies her resolve while inspiring her to reflect personally on proletarian hardships [19].

That said, Sofya's pseudo-feminist characterization falters when she observes that some behaviors, like "throw[ing] cigarette stumps any and everywhere," are especially unseemly "in a woman," demonstrating complicity in a traditional expectation for women to be cleanly and unobtrusive [19]. Still, she comments on the fine dress of "grande dame[s]," or middle-class women: "Do you think I always dress this way? I can't bear this fine toggery, this sumptuous rustle. A human being is simple by nature, and should dress simply—beautifully but simply" [19]. Sofya implies that women have no special obligation to dress more fancily than human nature warrants, an empowering sentiment considering the constrictive nature of women's clothes at the time. More figuratively, she suggests that elaborate etiquette, a social and behavioral "toggery" or vestment, to which higher-class women subjected themselves at the time, is unnecessary, as are the constrictive gender norms of the time.

This criticism of the habits of upper-class women doubles as Gorky's implicit indictment of bourgeois superficiality and artificiality. It goes without saying that Gorky frequently lambasted the upper classes, whom he conflated with capitalist decadence, and one criticism addresses the inflated grande dame-like culture with which he claimed the bourgeoisie obsessed itself. The bourgeoisie, he said, felt a

profound "obligation to defend culture," even though bourgeois artists translated the "corruption and meanness" of their lives into their work and espoused moral nihilism, demonstrating their fundamental indifference to culture [6]. On the other hand, the key to art—and dressing is a type of art—lay with the less sophisticated yet powerful collective, which from prehistory lay the foundations to "the history of world culture" [6].

In addition to commentary through figurative language and literary devices, the novel features moralistic passages that aim specifically to indoctrinate the reader towards socialist thinking. After Nilovna attends a funeral gathering at which the police attack and wound several townspeople, she conveniently reflects on the townspeople's "ability to recover from the horrible, an ability which clearly testified to their manly readiness to meet any demand made on them for work in the cause of truth" [19]. At this moment, since the reader has just learned Nilovna is wounded and is thereby invested in her welfare, the reader is especially attuned to her thoughts at the moment and vulnerable to the statement of Marxist morality.

Lacking as a result of this heavy-handed moralizing is verisimilitude, especially in dialogue. The novel is replete with lengthy monologues and exclamations decrying the repressive government, and even a coachman reflects articulately on the psychology of being an oppressor: "The rich man feels crowded, even in Paradise. That's the way it is. Once he begins to oppress, the government authorities are his friends" [19]. It is important to remember, however, that Mother is not Socialist Realist but proto-Socialist Realist, predicting some of Socialist Realism's core tenets. Mother may embody enough of these tenets to qualify as Socialist Realist, but one should keep in mind that Gorky did not intend it to be Socialist Realist when he was writing it. He may have intended to promote socialism, and he may have been working within a Chernyshevskian realist framework, but the concept of Socialist Realism did not exist in 1906, when he wrote the novel. That said, Mother certainly shares the same priorities of Socialist Realism: addressing facts "prompted by

reality” and “foster[ing] the proletariat’s revolutionary consciousness” over writing realistic dialogue [6]. If one wanted to call it Socialist Realist for that reason, as Clark does throughout *The Soviet Novel*, one would be amply justified. However, a proto-Socialist Realist characterization better takes into account the chronology of Soviet literature and greatly facilitates discussion of the ways *Mother* impacted the development of Socialist Realism.

## CONCLUSION

Socialist Realism is understandably perceived as an inflexible aesthetic imposed from the top down, but in fact, it underwent a complicated genesis and implementation. Drawing inspiration from Chernyshevsky’s interpretation of realism, Gorky—one of multiple intellectuals and writers associated with the Bolshevik Party—devised his own flavor of a Soviet state-sponsored aesthetic, which resembled Chernyshevsky’s realism but inserted a Marxist component. This flavor in turn saw itself reflected mostly accurately, yet imperfectly, in Gorky’s earlier work *Mother*, itself not Socialist Realist per se so much as a model for Socialist Realism, and *Mother* then indirectly influenced the themes of Socialist Realist literature through its implementation in curricula. At each juncture of thought, the main idea of realism, and eventually Socialist Realism, transformed. Yet Socialist Realism never lost the impulse it inherited from the nineteenth century to balance the accurate representation of realities with a subjective interpretation of those realities in literature. Not only did Socialist Realism not appear overnight, it drew from complex aesthetic thought dating half a century earlier: it is both unique to the Soviet Union and an inheritance from nineteenth-century Russia. ■

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# Creating Revolutionary Minds: An Analysis of Jiangxi Chinese Soviet Republic Marriage Regulation (1931-1934)

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The Jiangxi Chinese Soviet Republic Marriage Regulation (CSR, 1931-1934) not only regulated marital and familial affairs for individuals in the newly established party-state but was also an overture. It sought to liberate women from familial burdens, to recruit women join the revolution, to transfer labor and power from family units to the government and to restructure society around class-gender equality.<sup>1</sup> Most importantly, Marriage Regulation was an ideological discourse. By ideological discourse I mean the effort to imbue, educate, and invigorate illiterate, rural peasants with Chinese Communist Party (CCP) ideas. It intended to recode rural value systems to create a revolutionary force with "revolutionary minds."

My thesis, that the Marriage Regulation of 1931 was a vehicle for educating rural people into revolutionary equality, is clarified in the following arguments. I pose the following questions: What ideologies did the Jiangxi CSR Marriage Regulation intend to teach? Why did the CCP intend the CSR marriage regulation to enforce their general position? How exactly were ideologies encoded in the legal clauses and official interpretations? In this paper, I will argue that the promotion of gender equality and women's status were means to achieve unified support for the CSR and vice versa: the goal of expansion in the short-lived CSR initiated and laid foundation for the progress of gender equality in China via the 1931 Marriage Regulation.

## INTRODUCTION

The new regime in Jiangxi established and led by CCP was a foundation for further expansion into a national regime. With this national framework as a blueprint, the CCP launched class struggle, liquidating the bourgeoisie and transferring the power to the proletariat, in order to narrow the scope of potential supporters of the CCP and purify the potential revolutionary force. Within the eligible citizens, the CCP intended to maximize labor power of the state by assigning tasks in nation building and war preparation to both genders with equal significance.

The generalizations above are explicitly stated in Article 1, sentence one, of the General Constitution of Chinese Soviet Republic, "The mission of the General Constitution of Chinese Soviet Republic is to guarantee the sovereignty of the dictatorship of peasants and workers in Soviet region and to achieve its victory in the whole China [1]."<sup>2</sup> The self-declared regime did not contain its ambition within

a few counties in Jiangxi but set the goal of ruling to the whole China. Understandably, this goal did not only require party members' effort but, more importantly, due to the limited scale and influence of this young party, it required people's support. Unlike the Nationalist or KMT-led Republic of China, which only asked for people's acknowledgement and conformity, the CCP expected and needed nearly every citizen's active physical participation in specific state-building tasks including war affairs. And moreover, by initiating class struggle, the CCP narrowed their potential supporters to poor people, including poor peasants and workers, middle peasants, Red Army soldiers and their family members and so forth. In order to make the proletariat men and women devote their labor and commit to those changes voluntarily and wholeheartedly with minimal monetary return in a short time period, the CCP had to consistently and determinately implement their ideologies to its citizens.

Nation building tasks, as promised in the General Constitution, welcomed

and included women in heavier labor and intellectual work that aimed for economic construction and war preparation. For example, in terms of war preparation, while men were encouraged to join the Red Army, women were encouraged to provide food for Red Army, to do laundry for Red Army soldiers, sometimes even to deliver military information of the enemies for the Red Army and to personally persuade "White Army" soldiers to defect by talking to them as a woman. While men continued with their traditional role in heavy labor such as ploughing, women who participated heavy labor together

1 The term "class-gender" suggests that gender is always divided by class and class is always divided by gender. In the CSR case, not all women are eligible for the privilege of gender equality. Only the impoverished women or women in qualified classes were deemed as citizens of CSR and could enjoy the benefit of laws and policies.

2 Translated by the author. "Zhonghua siwei xian fa da gang 1931" 中华苏维埃宪法大纲 1931 [The General Constitution of Chinese Soviet Republic 1931], accessed November 25, 2017. Chinese text: 中国(华)苏维埃共和国国家根本法(宪法)的任务, 在于保证苏维埃区域工农民主专政的政权和达到它在全中国的胜利。http://cpc.people.com.cn/GB/64184/64186/66637/4489708.html

deemed as role models for other women, as evidenced by many official CSR documents from 1931 to 1934 [2].<sup>3</sup>

Gender division in labor in CSR demonstrated how the Soviet government intended to encourage people to participate a political and economic life in society outside the household. Within the framework of labor division, gender equality in CSR can be understood as equal opportunities for men and women to take on political and economic roles and equal credit for their participation, regardless of differences in physical contribution. The important point here is that using the principle of gender equality, tasks assigned to women were adapted to women's physical situation. While women's tasks were separated from men's, both genders received the same labor credits. It means, although women were assigned to do light labor work, the significance of the work was deemed no weaker than heavy labor conducted by mostly men. Note that it was the first time that the concept of gender equality was introduced to the Jiangxi Soviet area. The new concept was integrated in labor to empower women as well as to teach people the benefit of gender equality as part of the CCP ideologies.

Under the premises above, this paper will focus on the why and how the 1931 Marriage Regulation implemented CCP ideas to citizens in CSR, especially women, and will evaluate the effect and meaning of this marriage regulation. To this date the ideologies and ideology implementation in CSR have not been fully studied. M. J. Meijer's 1971 Marriage Law and Policy in the Chinese People's Republic, for instance, summarizes and analyses the history of the PRC marriage laws, policies and their applications from the the late Qing period to 1950. I accept Meijer's analysis of the Marriage Law of People's Republic of China 1950, particularly his general thesis that the CCP "does not apply the law only [to maintain social order], but applies it with the purpose of building socialism and instilling ideology [3]." However, he does not focus as tightly on the 1931 CSR law as I do.

Lucie Cheng's "Women and Class Analysis in the Chinese Land

Revolution," has also proven helpful to my research [4]. Particularly her analysis of why women's class status was not independent from family has provided insights into particular parts of the CSR. In her argument there were three approaches to distributing land from the Land Law in Jiangxi Period: the proto-feminist approach, the familistic approach and the synthetic approach. Cheng's work provided evidence for that argument that in 1931 some originally poor women may have used the law to divorce their rich husbands. The freedom to choose to divorce for sentimental or for practical reasons might have given rich and abused women way to leave a husband and the landlord class as the marriage policy evolved.

### IDEOLOGIES OF THE CSR IN THE CONSTITUTION

At The First National Congress of the Communist Party of Chinese Soviet Republic 中华苏维埃第一次全国代表大会 in 1931, the General Constitution of CSR was enacted to state the missions of this newly established regime. Apart from setting the tone and principles of this new regime, when presented to the public, those principles became political discourse that intended to educate people of CCP ideologies. Since there is rarely concrete or explicit evidence for the ideology implementation function of laws of CSR, it is my hypothesis that the rules and concepts in the General Constitution did not just intend to regulate people's behaviors and to structure the society but, more importantly, to restructure people's minds with CCP ideologies in order to ultimately win people's absolute support and expand the regime to the entire China area. As stated in the first clause of the Constitution, "The mission of the General Constitution of Chinese Soviet Republic is to guarantee the sovereignty of the dictatorship of peasants and workers in Soviet region and to achieve its victory in the whole China [1]."<sup>4</sup> As implied in Article 1, winning the absolute support of peasants and workers and expanding the CSR regime are the ultimate ideologies to be accepted and internalized by the public but there are as

I define "transitional" ideologies serving as not only as ends but also as means to achieve the victory of the regime at this period: class struggle, gender equality, racial equality and so forth.

The tone of the Jiangxi Soviet government was not peace and stability but struggle and war against everyone who was against the expansion of CSR until the final victory. Stated in Article 1 of the General Constitution, the purpose of the regime is to "eradicate all feudal remnants, cast out imperialists powers in China, unite China, systematically restrict the development of Capitalism, develop state's economy, promote the union power of proletarian and ideological level (jue wu cheng du), and unite the vast poor peasants around it, to transfer to the authoritarian regime of proletarians (wu chan jie ji zhuan zheng) [1]."<sup>5</sup>

Though not explicitly expressed, the focus of the statement on the purpose of the CSR regime was not building a new totalitarian regime for the poor peasants but, quite the opposite, uniting the poor peasants for state building. Although, as I indicated in the introduction to this paper, CSR promised and worked efficiently to emancipate poor peasants and workers from slavery and to give them the rights of a legal citizen, the emancipation was not the ultimate goal for CCP. Instead, CCP expected to acquire people's support in return for the expansion of the state and transformation of social structure. However, physical support out of mere reciprocity was not enough for the foundation of a newly-established state. In this process, reciprocity became a strategy beginning with changing people's attitude towards CSR, and thus ideology implementation was a vital component that intended to transfer people's motivation to join

3 Translated by the author. "Jiangxi su qu fu nv yun dong shi liao xuan bian" 江西苏区妇女运动史料选编 [Selected Works of Historical Documents of Women's Movement in Jiangxi Soviet Region], ed. Jiangxi Women's Federation and Jiangxi Archives 江西省妇女联合会 江西省档案馆 (Nanchang: Jiangxi People's Press, 1982): 16-20

4 Translated by the author. See note 2.

5 Translated by the author. See note 2 above. Chinese text: 消灭一切封建残余, 赶走帝国主义列强在华的势力, 统一中国, 有系统的限制资本主义的发展, 进行国家的经济建设, 提高无产阶级的团结力与觉悟程度, 团结广大的贫农群众在它的周围, 以转变到无产阶级的专政。

the uprising from self to the state and thereby to create the first army of true supporters of the CSR out of the people.

The General Constitution stipulated the eligibility of Soviet citizen:

The Soviet regime belongs to workers, peasants, Red Army soldiers and all laboring people. Under the Soviet regime, all workers, peasants, Red Army soldiers and all laboring people enjoy the right to elect representatives in charge of the management of the regime. Only warlords, bureaucrats, landlords, despotic gentry, capitalists, rich peasants, monks and all exploiters anti-revolutionaries do not have the rights to elect representatives to participate in the regime and the right of political freedom [1].<sup>6</sup>

People were classified by social class and only certain classes workers, peasants, Red Army soldiers and poor people could take part in the state's affairs. Even if the regime supported religious freedom, as stated in Article 13, it also gave people the "freedom to go against promotion of religions [1]." (反宗教的宣传之自由).<sup>7</sup> Here the regime even classified religions together with landlords as "exploiters" and "revolutionaries." This phenomenon suggests that the regime required people's full support both physically and mentally, which is probably why the CCP needed people to fully absorb its ideologies. The CCP also expected the ideologies to justify themselves when people started to believe them as truth instead of analyzing them logically.

With state-building being the important mission for CSR citizens and the state's main ideology, the claims of emancipation of poor people, the equality of people and emancipation of women are means to state-building process at this period and, as I define, "transitional" ideologies of CCP.

The concept of equality appeared the first time in the General Constitution in Article 4:

In the area of Soviet Regime, workers, peasants, Red Army

Soldiers and all laboring people and their families, regardless of gender, race (Han, Meng, Hui, Zang, Miao, Li and in China's Taiwan, Gaoli, Annan, ect.), religion, are all equal in front of the Soviet laws and are all citizens of Soviet Republic [1].<sup>8</sup>

This article suggests that equality is not universal. Only the legal citizens, as discussed previously who belonged to certain social classes, were entitled to be equal in front of the Soviet laws.

In conclusion, stated explicitly in the General Constitution of CSR, the ideologies of CSR that were intended to be implemented to the public as political discourse are to win absolute support from citizens to ultimately establish regime across China by eradicating feudal remnants from the outside and class struggle from inside. Inequalities

“ Although gender and racial equality was promoted in CSR, the definition of equality was not universal.

were only to be eliminated on gender and racial levels but class struggle was in itself unequal. It means that, although gender and racial equality was promoted in CSR, the definition of equality was not universal. Also, it is worth noticing that freedom and equality (on gender basis) probably will become or have become higher ends of the regime under CCP. However, in Jiangxi period, the beginning of the CSR regime when those grand goals were not able to be fully realized, were means or ideologies to be implemented in order to win people's absolute support for state-building. In the next part of the paper, I will discuss why and how these ideologies were implemented through Marriage Regulation in 1931 as discourses in both the content of law and in conversations between citizens and government.

## INTRODUCTION TO 1931 MARRIAGE REGULATION

One the of most distinguishing

characteristics of the CCP Marriage Regulation in 1931 was its conciseness. The Marriage Regulation only covers 23 articles in total and all of them only stated general principles instead of detailed stipulations, different from family legislations in Soviet Russia or in Nationalist China. This characteristic of Marriage Regulation in 1931 extended to most of the subsequent regulations and laws promulgated by CCP even in later periods [3]. Even though the lack of clarifications in the Marriage Regulation may suggest that the legal system of Jiangxi recognizes cases as source of law, for the public, the enacted law and other legal documents could be easily understood and internalized as guiding principles by general public. Since the public was mostly uneducated and with rare access to others forms of education or ideologies outside CCP region, assisted with practical benefits, those CCP ideologies could be easily interpreted as "justice" or even "truth" for many people, particularly the young. Therefore, the conciseness of the law is the first clue pointing to the argument about ideology implementation.

However, I will not be able to present evidence on how the CCP propagated the law to CSR citizens and whether the local people truly embraced and supported the CCP rule. No documents that I have studied so far explained the propagation process and people's reactions. The research on this question is not included in this short paper but will be part of my larger research project. In this paper, I am only postulating such intentions of ideology implementation from laws and official documents.

6 Translated by the author. See note 2.

Chinese text: 苏维埃全政权是属于工人, 农民, 红军兵士及一切劳苦民众的。在苏维埃政权下, 所有工人, 农民, 红军兵士及一切劳苦民众都有权选派代表掌握政权的管理; 只有军阀, 官僚, 地主, 豪绅, 资本家, 富农, 僧侣及一切剥削人的人和反革命分子是没有选派代表参加政权和政治上自由的权利的。

7 Translated by the author. See note 2.

8 Translated by the author. See note 2.

Chinese text: 在苏维埃政权领域内的工人, 农民, 红军兵士及一切劳苦民众和他们的家属, 不分男女, 种族 (汉, 满, 蒙, 回, 藏, 苗, 黎和在台湾的台湾, 高丽, 安南人等), 宗教, 在苏维埃法律前一律平等, 皆为苏维埃共和国的公民。

## AUTO-CRITIQUE OF EFFORTS TO CARRY OUT WOMEN'S EMANCIPATION

Despite the great effort in restructuring people's mind and society, CCP did not succeed in completely freeing women from the household and gathering their support for the Red Army. Both contemporary scholars and authorities of the period found/acknowledged that the efforts to empower women were unsuccessful. As a document said, "So long after the Marriage Regulation was enacted, not only did the counties execute it carefully, they also did many things violating the Marriage Regulation [2]."<sup>9</sup> The evaluation from the authorities may suggest that CSR government did attempt to enforce the marriage law practically and strictly but the critique also suggests that the ideologies involved in the marriage were not successfully implemented and accepted by women either.

For example, only the pioneering female revolutionaries started to or were able to follow the terms on the General Constitution and contribute to state-building process by propagating socialist ideologies, taking care of the Red Army soldiers or even joining the battles. However, some women were still living under the pressure of patriarchal power, as it was even stronger than the revolutionary tide. As reported in the January 1933 "Report from the Department of Youth Women of the League Bureau in Hunan and Jiangxi Area" 1933年1月 湘赣苏区 团省委青妇部报告, tongyangxi (foster daughters-in-law) are still abused. Among the 15 fatal incidents caused by abuse, some were beaten by husbands and one was brutally murdered by parents-in-law. Also, some women did not form the revolutionary and socialist mind. In the same report, in some cases women threaten to divorce her husband who wanted to join the Red Army [2].<sup>10</sup> From the evidence above, I cannot give much credibility to the statistics of divorce rate presented by officials since the numbers could be mere propaganda.

However, knowing that the work on women was not successful, the administrative did not give up on ideology implementation.

In another critique:

The women-work in the Soviet region, among all the work on people, is the worst. No matter in the Party or the League of Youth, seldom were women rising up against all feudal traditions and conventions. Only by making them, like men in the land reform, eliminate feudal traditions in the land reform, struggle against rich peasants, is the only way to emancipate them. Therefore, women in soviet region has a very weak concept about joining the revolutions... These odd phenomenon prove that women in soviet region are still controlled by feudal thoughts. It proves our fault of the negligence to women's movement, not attracting them to join the anti-feudal struggle and freeing them from feudal influence [2].<sup>11</sup>

The above evaluations indicate that women were also expected to join the class struggle but they were not successfully motivated to do so. However, even this critique was used as a method of ideology implementation. The idea and logic behind the words completely deserted traditional social norms and attempted to enforce a CCP norm by claiming the habitual actions as "odd phenomenon" and by criticizing the lack of revolutionary minds among women in Soviet region. Therefore, the government seized every chance to promote CCP ideologies even in the critiques of the work on ideology implementation for women.

The 1931 Marriage Regulation, as the first formal statewide marriage legal policy laid foundation for later marriage and laws and was only the starting point of a series of prolonged trials of marriage policies. Despite its problems and shortcomings, the 1931 Marriage Regulation of CSR in Jiangxi formally initiated the CCP's campaign and devotion to female empowerment and gender equality as means to expansion in soviet period or possibly as higher end in later periods.

On the basis of the reports above, I hypothesize that using ideologies to unite people and gather military forces is probably a constant strategy, independent from practical changes of politics or results of the policies. One must realize that ideologies implementation is a difficult and prolonged but necessary process at the beginning of state-building, especially

when government expected its citizens in Jiangxi area to interpret real loss, such as man losing control over decisions of his wife or losing life in a battlefield, as necessary sacrifice for higher purpose. Therefore, despite of the obstacles from my observation, the CCP never forwent their effort in ideology implementation and the CCP seized every conversation with public as a chance to enforce the political discourse into their minds.

## FREEDOM OF MARRIAGE AND EMANCIPATION WOMEN

In the next sections, I will explain how ideologies were implemented in 1931 Marriage Regulation via its content and related official documents. With the evidence, I attempt to show that the CCP intended to use the 1931 Marriage Regulation, marriage policies and other documents to convince the public of the justice of policies and legitimacy of the CCP rule.

Stated in Article 11 of the General Constitution is the following:

The Chinese Soviet Republic aims to completely execute the emancipation of women, acknowledges marriage freedom, practices various methods to protect women, to enable women to practically gain material foundations to gradually disengage with household constraints and to participate the economic, political and cultural life in society [1].<sup>12</sup>

This clause suggests that the purpose of the sovereignty and the law is not promoting women's wellbeing in a

<sup>9</sup> Translated by the author. See note 3, 70. Chinese text: 婚姻条例颁布了这样久,各县不但没有切实执行,而且还做了不少的违反婚姻条例的事情出来。

<sup>10</sup> Translated by the author. See note 3, 276-277.

<sup>11</sup> Translated by the author. See note 3, 57. Chinese text: 苏区的妇女工作,在群众工作中,是做的顶坏的,不论在党和团,都很少领导妇女起来反对一切封建的风俗和习惯,使它们在土地革命终于男子一样的起来参加产出封建,反对富农的斗争,指示出妇女只有这样,才是唯一解放她们的出路,所以苏区妇女,对革命斗争参加的观念,非常薄弱.....这些怪现象证明苏区的妇女,仍被封建思想统治着,证明我们过去对妇女运动的忽视和不注意的错误,没有吸引他们参加反封建的斗争,使她们从封建影响下解放出来。

<sup>12</sup> See note 2 above. Chinese text: 中华苏维埃政权以保证彻底地实行妇女解放为目的,承认婚姻自由,实行各种保护妇女的办法,使妇女能够从事实上逐渐得到脱离家务束缚的物质基础,而参加全社会的政治的文化生活。

lifestyle of their choice but to motivate women to take a political life which is the revolution. CSR gives female liberation a direction which is motivating women to participate the state-building process. In other words, state-building is the ultimate purpose of female liberation which also proved my argument that in Jiangxi Period, the goal of emancipation of women is mere means and an ideology to achieve the expansion of CSR.

This article in the General Constitution stated the reason for marriage freedom and described the goal for the Marriage Regulation. The first article of Marriage Regulation underscores freedom of marriage as the principle upon which the whole marriage regulation builds and claims to abolish the feudal system of marriage signified by those involuntary contractual marriages.

#### Article 1:

The principle of freedom of marriage between man and woman is established and the entire feudal system of marriage arranged by persons other than the parties themselves, forced on the parties and contracted by purchase and sale is abolished. The practice of taking a 'foster daughter-in-law' is forbidden [2].<sup>13</sup>

According to Meijer, "in the 'feudal marriage system' was included the system of paternal arrangement of marriage, marriage concluded under coercion, and marriage 'by purchase and sale;' all the elements that typify the traditional family in the Communist view as 'feudal [3].'" However, this "feudal" system of marriage is not just a set of physical rules and rituals but more importantly, the conventional or "traditional" ideology centered on parental and patriarchal power within family unit. In this first clause, the CCP attempted to convey that the changes they intended to make on marital affairs was not a peaceful process but a reconstruction of the whole marital rules and power systems after completely destructing the existed one for right purposes. As Meijer argues, "Article 1 of Kiangsi law is a political battle cry [3]." Therefore, by pitting old marital practices against freedom and

by instilling the concept of "fighting for freedom" as good, the change that the new regime was about to make on women's life suddenly became exciting instead of terrifying. The elevated fighting spirit among women might have led to the divorce rate initiated by mostly women in the Soviet region.

### AGE LIMIT FOR MARRIAGE

The law created opportunities for young people to fully absorb CCP ideologies so that ideological implementation on an individual level could be amplified to the family level through new marriages of the next generation. In Article 4, CSR specifies the age limit for marriage as fully 20 for men and fully 18 for women. Compared with either Qing law, where there was no legal age limit and young girls could be married off as foster daughters-in-law (*tongyangxi*) and betrothed to another family at early age, or Republican Marriage Law, where girls could engage at 15 and marry at 16, this higher age limit set by CSR could protect young people's marriage and autonomy from being intervened in by parents [3]. More importantly, by postponing the age of marriage, individuals would be exposed to government propaganda for a longer time before forming a family. Since economics of CSR still operated under the family unit, on the one hand, the newly established families united under CCP ideologies were able to conduct coordinated economic construction and war preparation under CCP's instructions or guidelines. On the other, citizens of CSR could be better controlled and united by the party-state.

Moreover, the cultivation of socialist minds was not confined to formal education and regulations but also permeated in leaders' conversations with citizens. The administration received complaints from male citizens on the adjustment of the age limit since because of the enactment of the law, they had to marry later than we could before.

Mao responded to such complaints presented by a delegate in On the Conclusions of the Report from Central Execution Committee and People's Committee 关于中央执行委员会和人民委员会报告的结论, quoted in Zhang Xipo, History of Chinese Marriage Legislation (Beijing: People's Press, 2003), 149. Chinese text: 关于法定最低婚龄问题, 结论指出: 关于结婚的年龄问题不少同志主张降低。这种意见, 我觉得是不妥的。为了种族的与阶级的利益, 结婚年龄不应该低于男20岁, 女18岁以下。应该明白早婚是有极大害处的, 同志们! 要耐烦一下了! 以前在地主资产阶级统治下, 贫苦工农有到四五十岁还不能结婚的, 为什么现在一两年都等不及呢?

About the age limit for marriage, quite a few comrades suggest that it should be lowered. This kind of opinion is not appropriate. For our state's and class' benefit, legal age for marriage should be no lower than 20 for men and 18 for women. We should be clear that early marriage is extremely harmful. Comrades! Please be patient! In old days under the rule of landlord capitalist, some poor peasants and workers couldn't even marry until their forties or fifties. Why can't you wait one or two more years? [5]<sup>14</sup>

In administrators' view, the meaning of class struggle transcended individual needs and individuals should sacrifice for the sake of the revolution and the class. However, the purpose of such statements is not just a conclusion for the current policies but more importantly, it is a conversion with people that directly convey CCP ideologies and educate the public by enforcing such a socialist ideology into citizens' mind to artificially build their socialist mindset. Not only was the discourse built in the laws on state level but also permeated in the communications between the authorities and the public in the context of many cases other than age limit.

### BANNING DOWRIES AND MARRIAGE PRESENTS: A CONSCIOUSNESS RISING

While Article 1 stated that the purchasing of marriage was banned, Article 8 re-enforced this stipulation

13 Marriage Regulation of CSR 1931 is provided in Selected Works of Historical Documents of Women's Movement in Jiangxi Soviet Region. See note 3 above. Translation is provided by Meijer in his book. See note 4 above, Appendix I. Chinese text: 确定男女婚姻, 以自由为原则, 废除一切封建的包办强迫和买卖的婚姻制度, 禁止童养媳。

14 Translated by the author. Mao Zedong, On the Conclusions of the Report from Central Execution Committee and People's Committee 关于中央执行委员会和人民委员会报告的结论, quoted in Zhang Xipo, History of Chinese Marriage Legislation (Beijing: People's Press, 2003), 149. Chinese text: 关于法定最低婚龄问题, 结论指出: 关于结婚的年龄问题不少同志主张降低。这种意见, 我觉得是不妥的。为了种族的与阶级的利益, 结婚年龄不应该低于男20岁, 女18岁以下。应该明白早婚是有极大害处的, 同志们! 要耐烦一下了! 以前在地主资产阶级统治下, 贫苦工农有到四五十岁还不能结婚的, 为什么现在一两年都等不及呢?



by banning marriage presents and dowries, which were deemed as monetary transactions in marriage and a price tag for brides. The whole idea of banning purchasing marriage was to emancipate women from contractual marriage and also to diminish the clan power system formed through marriages. Thus, Article 8 also required marital registration as a symbol of government-approved marriage that replaced the authorization from patriarchal leaders in both families [3].

Under the requirement to register marriage, a contract is only effective when authorized by the municipal soviet. Practically, the registration process keeps track of marriage record of each person and thereby strictly guarantees monogamy. It also transfers the right of authorization from parents to government to prevent parental interference. However, the process of registration was more than an additional condition for marriage that physically guaranteed the freedom of marriage. Symbolically, the registration process with local government allowed marriage to be deemed as a right given by government instead of a natural right and put CSR government in a powerful place that controlled people's life. Marriage, in Qing dynasty and further back, had been contracted by parents from two families. It was more than forming an individual relationship but tying the relations between clans more closely to increase the power of clans and patriarchal controls. Marriage rules and rituals were stipulated by Li (a series of rites and rituals that were established to enforce a social order and morality) and should be carried out properly by worshipping Heaven or god, ancestors and parents. Thus in Qing or namely "feudal society" in CCP's definition, a marriage was authorized by parents or clans, Heaven and li, which separately represents patriarchal power, godly power and the power of social convention or morality. The CSR government, by stipulating marriage registration as the only authorization for a legal marital relationship, attempted to replace those three powers with the CCP authority so they might ideologically destruct feudal beliefs and transfer the power to the regime. A simple stipulation in law, again, did not only intend to regulate people's marital affairs but also build a powerful image of CSR in people's

mind.

The same article states that marriage presents and dowries are completely abolished. There are several practical meanings for this stipulation. Firstly, marriage presents were often viewed as price of a bride and dowries were a monetary weapon to protect the bride in the new family. When "purchase and sales" was forbidden, ideally, both the harm from money and the need for protection with money were eliminated in marriage. Secondly, in old society, the amount of wealth decided people's eligibility to get married, hence why most poor peasants were not able to get married [2]. By banning the terms on wealth, all legal citizens had equal opportunities to get married and thereby freedom of marriage was guaranteed and strengthened. However, it is worth noticing that the stipulation appears right after the marriage registration clause in which the government intended to guarantee monogamy and replace the power of clan, god and ritual. Note that the 1931 Marriage Regulation might only be proof that the government's ideologies were beneficial in theory instead of in reality because nothing in this law could force people to physically abide by it. Punishments for violating the regulations were never specified in this law, except that in Article 22 - "Whosoever contravenes this law shall be duly punished according to the criminal law [3]."<sup>15</sup> To my knowledge there was no separate canon of criminal law on state scale. The conditions suggest that military law covered civil criminal infractions but this matter must lie beyond my scope for the moment. What can be said is that the real function of the 1931 Marriage Regulation was educational rather than punitive. It was ideology implementation instead of direct behavioral modification.

### FREEDOM OF DIVORCE

Also unique to the CSR Marriage Regulation compared with previous marriage laws in China is the statement

on divorce. According to article 9, instead of an eventual mutual agreement or a formal divorce litigation procedure initiated by one party, divorce could be decided and enforced by either party of the couple immediately while the other party has no right to refuse such a claim [3].<sup>15</sup> This article responded to the General Constitution perfectly since the freedom of divorce gave women concrete opportunities to escape from traditional female roles within the household to participate the "economic, political and cultural life in society [1]."<sup>16</sup> Also, with freedom of divorce, women who suffered in silence from an unsatisfactory marriage and a controlling husband, especially foster daughters-in-law who were sold to another household at young age to serve the household until she and her husband were able to consummate the marriage,

“ The real function of the the real 1931 Marriage Regulation was educational rather than punitive. It was ideology implementation instead of direct behavioral modification.

were able to seek new possibilities in their lives other than taking care of domestic affairs.

Secondly, according to Meijer, "the Regulations not only abolished the shackles of the traditional family but in fact it did away with the shackles of the family altogether and created the possibility of a family-less society [3]." This argument is only partially true in legal codes. I would argue to the contrary that the state did not intend to create a family-less society because the economy of CSR still operated under the family unit as stated in the previous section. Leaders of CSR only intended to eliminate traditional families under clan power via Marriage Regulation. Therefore, newly established families that might have benefited more from CCP policies and were better

<sup>15</sup> Translated by Meijer. See note 13 above.  
Chinese text: 违反本条例的，按照刑法处以应得之罪。

<sup>16</sup> See note 2 above.

educated with CCP ideologies were more likely to be composed of supporters of the regime. Under the new structure, the new regime led by CCP would be able to expect a purer and stronger support from its citizens of both genders for war preparation and economic construction.

Freedom of divorce could also be an opportunity for women to disentangle themselves from their identity as a landlord or part of the rich peasant class and thereby benefit from land policies. As Cheng explained in her paper, policies on women's class status had been modified multiple times from 1928 to 1933 in Jiangxi Soviet period. The land was confiscated by the government and redistributed indiscriminately by "the number of population in an area, regardless of age, gender, or class background [4]." Under these regulations, women were entitled to the same amount of land distribution as men despite of women's relatively smaller labor force. However, the 1931 Regulations of the Jiangxi Soviet Provincial Government for the Confiscation and Redistribution of Land stipulated that "wives, daughters-in-law and daughters of landlords should not receive and land in the redistribution. This also applied to those who married poor peasants [4]." At this point, inter-class marriage would not help reclassify wives or daughters from landlord class or rich peasant class and retain their family's property because class of one's original family was the only criterion. This situation changed in 1933 when "How to Analyze the Classes and Decisions Concerning Some Problems Arising from the Agrarian Struggle" authored by Mao included three factors to decide the status of a woman in inter-class marriage: the time of the inter-class marriage (before or after the Uprising), the class of a woman's original family, the amount of labor contributed by a woman [6]. The new policy implied that a woman was able to change her class through interclass marriage when she labored or ceased laboring for a certain amount of time in the new family.

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new policy implied that a woman was able to change her class through interclass marriage when she labored or ceased laboring for a certain amount of time in the new family.

A document drafted in October 1933 by the Central Government of the CSR, "How to Analyze the Classes and Decisions Concerning Some Problems Arising from the Agrarian Struggle," described the change of class due to marriage in great detail. For example, as stipulated in Article 15.4, if a woman from a landlord family married a poor peasant and contributed her labor as a source of income of the family for five years, she was able to be recognized as a member of the poor peasant class. For another example, in Article 15.3, if a woman from a poor peasant family married a landlord family before the Uprising, she would not be considered as a member of landlord class unless she ceased laboring for five years. And if she married after the Uprising, according to Article 15.4, she did not have to change her class status at all [6].<sup>17</sup> The examples illustrated that the 1931 Marriage Regulation gave married women an opportunity to change their class by divorcing their landlord husband and marrying a poor peasant. This benefit for women was not predisposed in the 1931 Marriage Regulation intentionally for class struggle but consequently the policy on marriage did not only give women additional physical protection in class struggle with marriage policy, but also encouraged and assisted women to follow the CCP ideologies.

Interestingly, the discourse did not stop there. Again, the authority took the opportunity of communicating with public and furthered the ideology implementation in their conversation. In February, 1932, "Inquiries on the Marriage Regulation," someone wrote an anonymous letter questioning some clauses in the CSR marriage regulation, including a clause about freedom of divorce. "If one is allowed to divorce without reasonable

17 "How to Analyze the Classes and Decisions Concerning Some Problems Arising from the Agrarian Struggle." (中华苏维埃共和国中央政府关于土地斗争中一些问题的决定) Selected Documents of Chinese Communist Party Central Committee 9 (1933) 中共中央文件选集九(1933) <http://cpc.people.com.cn/GB/64184/64186/66639/4492405.html>

18 See note 11 above, 145. Chinese text: 革命革割革绝, 老婆都革掉了

excuse, based on the insufficient level of education of people, many people will constantly change partners. This situation had already happened many times in Yongding County. How do we solve this problem after all?"

Xiang Ying, the Vice President of the CSR, addressed this issue publicly:

This is KMT view. It is a pedantic old man's words to support feudal system while insulting women. Those male comrades, please don't be afraid, we are exactly intending to eradicate feudal remnants completely and eliminating the feudal thoughts from our minds using cases like those. There are some women who are unwilling to divorce but it is the minority. Most people against (freedom of divorce) are men. [2]<sup>19</sup>

In Xiang Ying's explanation, it clearly interpreted the matter "constantly changing partners as liberation" and "staying in one family" as feudal thoughts that is used to control women. Again, similarly to the communication on the matter of legal age, the authority attempted to educate the public that they were supposed to take satisfaction in the success of revolution in general which is the eradicating feudal remnants and establishing new order, instead of obsessing with personal loss and gain. Even in front of doubts, the CCP never ceased cultivating revolutionary minds in the public.

## CONCLUSION

"A single spark can start a prairie fire," a classical allusion to the Confucian classic *Shangshu*, became a popular proverb after Mao Zedong used it in his public letter to Lin Biao in 1930.<sup>20</sup> In the letter, Mao recognized the increasingly intense conflicts between classes such as strikes and uprisings. He was convinced that the chaotic situations were like "dry wood" that could be lit by a hint of revolutionary ideas and could unavoidably evolve into "an anti-imperialism, anti-warlords, anti-landlords revolution [7]."<sup>21</sup> With the ambition to expand the regime led by CCP to the whole of China, the CCP in Jiangxi soviet period set the fire with land reform that deepened the class conflicts and ideologically purified the CSR citizens. After that, the "women's movement," with the Marriage Regulation 1931 as a backing agency, created class-gender identity and attempted to implement CCP ideologies in individuals. Explained in this paper, the legal clauses on the freedom of marriage, freedom of divorce, the age limit and the ban on dowries intended to destroy clan power and restructure society with new families that benefitted from the CCP policies and supported the new regime. Besides the legal code, the CCP also educated the public through communications such as speeches, published documents, magazines, school education and so forth in order to unite people under the same belief and to strengthen the revolutionary army.

The strategies executed in Jiangxi were among the first round of experiments

in recruiting supporters and managing local people. Only after years of strategy revisions in various regions did the CCP determine the strategy, "Encircling the Cities from the Rural Areas" (农村包围城市) to fulfill the CCP's goal of building a national regime. However, even if the concept of gender equality was propagated to people mainly to encourage women to join the revolution as labor force, the process exposed women, especially the impoverished, to opportunities to escape traditional gender roles and duties, acquire a social identity, and find husbands of their own choice. The ideologies of CCP implemented in Jiangxi Soviet regions showed women a way and possibility to make changes in their lives in their own hands. ■

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<sup>19</sup> Translated by the author. See note 3 above. 关于婚姻条例质疑. 50-51. Chinese text: 如果无论任何一方, 没有正当理由都准许离婚时, 则在目前群众教育还很薄弱的时候, 朝秦暮楚之事, 必然要发生出来。且这种现象, 现在永定各地已经发生, 究要如何解决? ... 这是国民党训政宪政的观点, 是维持旧礼教老冬哄先生所侮辱女子的话, 说有这些思想的男同志, 不要害怕, 我们正是从这些上面更去摧毁封建制度的残余, 以及肃清存留在我们脑筋中的封建残余思想, 坚决拥护离婚自由。至于女子不愿离婚的虽有, 但是少数, 绝大多数反对的是男子。

<sup>20</sup> Mao altered the sentence and the meaning of the text. The original text in *Shangshu* expresses: "If a fire is burning on a prairie, one cannot go towards it but it can still be put out." (若火之燎于原, 不可向迩, 其犹可扑灭) Mao only adopted the first part of the sentence to express a positive attitude towards the victory of the CCP regime.

<sup>21</sup> Mao Zedong, "A Single Spark Can Start A Prairie Fire," January 5, 1930. This was a letter written to Lin Biao to respond Lin's questions on how to evaluate the prospect of the Red Army.

LILLIAN  
LIN

Lillian (Xiying) Lin is a senior at Rice University majoring in Statistics and Asian Studies. She discovered her interest in gender issues in the field of modern Chinese history and literature late in her undergraduate years. This paper is the result of her first historical academic research, in which she reviewed a series of marriage laws and policies from the Qing Dynasty to the establishment of People's Republic of China. Currently, she is researching the influence of Cultural Revolution on gender equality, especially the modern operas adapted by Jiang Qing. In the fall of 2018, she will be pursuing a master degree and is seeking a suitable PhD program in East Asian gender history.

# How to Promote Healing 'Beyond the Scalpel': A Doctor-Patient Communication Model

AVI KAYE, STANFORD UNIVERSITY

In the rehabilitation process, a patient's physical restoration is inextricably linked to the psychological aspects of healing. A doctor's approach to communication significantly impacts their ability to garner essential diagnostic information and insight into the patient's emotional state. Despite the evident importance of productive communication, research shows a disparity between physicians' self-impression of their efficacy and empathy in conversation and clients' expectations of their caregiver's demeanor (Stewart, 1995). Additionally, there is a lack of consensus in the medical community over the most important aspects of communication to teach physicians ("Communication in Medicine," 1999). Accordingly, in this study, we determine the best practices for doctor-patient communication and create an original model for physician consultations that optimizes patient outcomes. The framework will integrate research from a variety of fields investigating the elements of communication that enhance long-term rehabilitation both in physiological markers and in subjective 'perception' of treatment success. For our model, we will focus on three main components:

Patient Participation;

Information Flow: Trust, Informational Support and Emotional Support;

Emotional Regulation: Clinical Empathy and Cultural Recognition.

*In the hospital setting, effective communication may be a key determining factor for a patient's recovery prospect. In February of 2017, I witnessed the outcomes of a life-altering traumatic event befall a loved one. I first received the message through a cryptic text: "Your brother was in a car accident." No further details. After several hours, I learned about his rapid extrication from the scene, emergent transport to the emergency room, and numerous urgent procedures that followed in the ICU. For days, my brother, the lone survivor of the accident, was treading the line between life and death, undergoing numerous tests, procedures, evaluations and high-stake decisions. Miraculously, my brother achieved a complete*

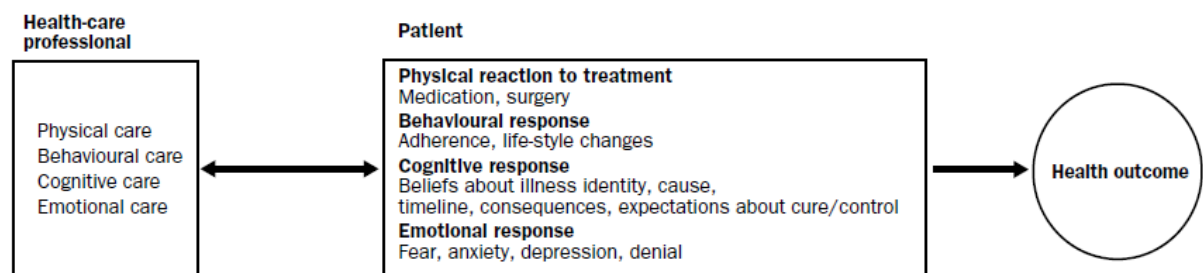
*recovery, and throughout the process, he attributed his resilience to the doctors who provided expeditious treatment and the empathetic communication that permeated his recuperation. His poignant narrative and the stories of many unlikely recoveries speak to the core of communication's potential and the need to study the optimal manner to approach the doctor-patient interaction.*

My brother's traumatic event instigated a protracted physical and psychological healing process marked by extended time in the hospital and perpetual medical attention. Every day, countless individuals must face similar challenges. Because of the hospital's nearly ubiquitous role in modern life, when in need of healing, every person

has a stake in the quality of treatment that is provided; as such, we want to ensure that health providers engage with patients in the most effective manner. Moreover, to augment the standard of care across our health system, any citizen dependent on healthcare services needs to be aware of the best practices in the clinical setting and understand the reciprocal nature of the doctor-patient relationship.

Throughout healing process, patients must work to restore both their physical vigor in addition to their psychological and emotional well-being [1]. (See Figure 1)

In the clinical setting, doctors constantly communicate with their patients to diagnose issues and to



**Figure 1.** Graphical depiction of care factors affecting health outcomes. Beyond just physical healing, patients also require multiple dimensions of psychological and emotional care from hospital staff [1].

provide the appropriate treatment. But the additional purpose of this interaction is to give therapeutic instruction and to foster a productive, mutual relationship. Despite the evident importance of the doctor-patient relationship, many doctors “in general are trained to conceptualize the mind and body as separate entities, thereby establishing an artificial dichotomy” [2]. As a result, communication remains a secondary feature of medicine and an aspect of care that often fails to meet the requirements of patients. Therefore, in our research, we will strive to answer the fundamental question: What are the best practices for doctor-patient communication that measurably improve immediate and long-term patient outcomes?

Our study will begin with an overview of the widespread problems impeding effective communication. Subsequently, we will aim to resolve the lasting complications with the doctor-patient relationship by exploring the fundamentals of an effective interaction, and then integrating insight from numerous disciplines into a unified model for physicians. Additionally, I conducted interviews with two experts in the fields of biomedical ethics and medical school curricula to help enhance our understanding of the best communication practices. In order to narrow the focus for our communication framework, we will utilize case studies on trauma patients that illuminate the best conversational practices. Traumatic rehabilitation poses many of the gravest and most complicated situations faced in the hospital, and the severe nature of these cases will help us create the most effective framework. The main categories that we will investigate are:

- 1) Patient Participation;
- 2) Information Flow;
- 3) Emotional Regulation.

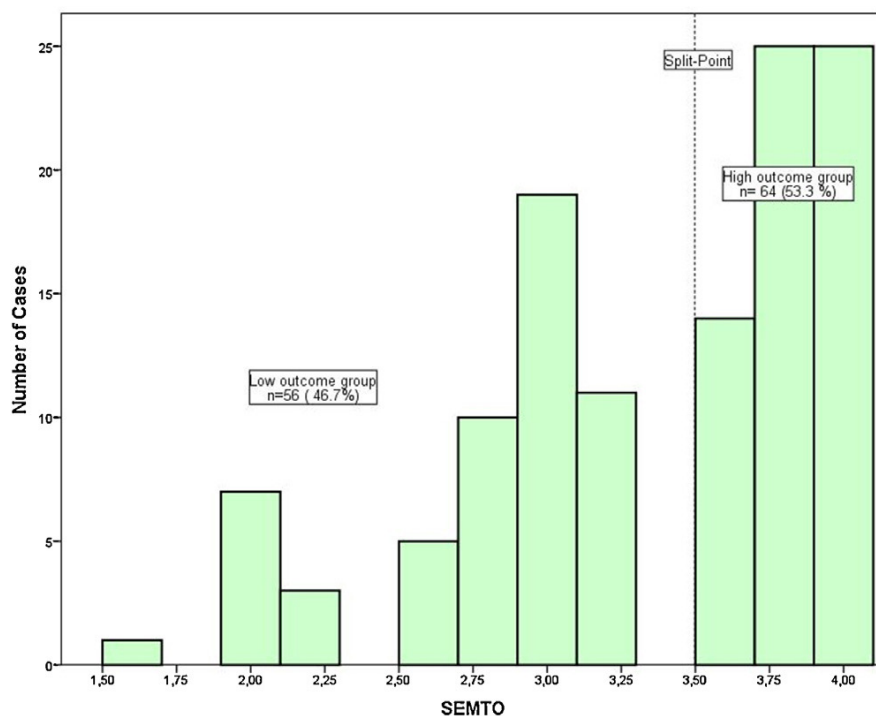
Our analysis will conclude with the anticipated clinical outcomes of our model based on previous research. Although our framework is created for doctors, because every citizen is a stakeholder in medical practice, it is beneficial for everyone to understand their privileges and their roles in a superlative relationship.

## CURRENT PROBLEMS WITH DOCTOR-PATIENT COMMUNICATION

Numerous studies show that effective doctor-patient communication is paramount in the healing process for traumatic injuries [1][4][5]. Yet, there are fundamental issues with physicians' general conversational practices described in one report as “problems of diagnosis, a lack of patient involvement in the discussion or the inadequate provision of information to the patient” [3]. Because of the medical discipline's dependence on empirical data and evidence, many doctors neglect to reinforce skills for dialogue and consequently overestimate their ability to communicate effectively. In one survey-based study, 75% of orthopedic trauma surgeons self-reported ‘satisfactory’ communication, but only 21% of the patients concurred that the doctor conversed effectively [5]. Many physicians' fruitless conversational conditions pose grave consequences for the evaluation and treatment of patients involved in serious trauma. For instance,

questionnaire-based investigations find that up to 54% of patient concerns are not addressed in consultations, 50% feel uninformed, and over half of the time, the doctor and the client do not even agree on the main problem [3]. There is also a recurring issue with physicians' approach to relationships with their patients. According to a recent report, using “Subjective evaluation of medical treatment outcomes” (SEMTO) survey scores from rehabilitating trauma victims, a staggering 20% of patients feel like their physicians are “not so empathetic” and almost half report dissatisfactory empathy scores [6]. (See Figure 2)

In post-treatment interviews, patients undergoing invasive long-term interventions consistently desire productive relationships with their doctor, but are often absent the basic gestures of empathy, emotional recognition or incentives to participate in decisions [6]. There is a broad variety of causes for these issues. Two main contributors are: varied medical school curriculums and a competitive physician environment [7].



**Figure 2.** “Subjective evaluation of medical treatment outcomes” (SEMTO) scores are patient surveys that evaluate the quality of interaction with physicians on a five-point scale. The graph shows a distribution of SEMTO scores from trauma patients after discharge from the hospital. 20% of the values fall in the “not so empathetic” range and over 50% below “satisfactory” (set at score of 3.5) [6].

## **VARIED MEDICAL SCHOOL CURRICULA**

In North America, medical schools adopt a predominantly information-based curriculum, prioritizing clinical knowledge over bedside manner [8]. While most programs implement some type of communication component into the course of study, the time on the subject is early in training and often integrated into practice of other skills. Medical schools nationwide are actively striving to amend their course curricula to account for the gap in the doctor-patient relationship. While individual schools are making strides to improve programs, there is still no standardized structure for doctor-patient interaction. Merely 31% of North American medical schools report integrating an accepted “model” for communication instruction [8]. Experts in communication training assert that “without a framework to help structure and focus attention on communication, the teaching is likely to be inconsistent and ineffective” [8]. To learn more about how medical schools are trying to counteract communication deficiencies, I conducted an interview with a curriculum specialist at Stanford Medical School. The interviewee explained that Stanford’s medical program aims to incorporate both a classroom ‘patient interaction’ component in the first two years called “Practice of Medicine” and a clinical-based communication training for the final three years (M. Sow, personal communication, November 27, 2017). The goal of this structure is to give students the skills and the language to converse with patients early in their experience before expecting them to garner information from real people. Stanford’s approach to training sets an important precedent for promoting effective communication and our model will help enhance similar existing practices.

## **COMPETITIVE MEDICAL SCHOOL ENVIRONMENT**

Following doctors from the start of their career, longitudinal studies of self-assessed empathy scores in medical school students consistently show a significant decline in quantitative empathy metrics [9]. Why do we observe

a pattern of waning empathy from physicians? A review by the Association of American Medical Colleges describes a phenomenon called the “hidden curriculum” that forces students to experience distress in order to improve as physicians [9]. After any person endures adverse conditions - which in medical school and residency includes demeaning and abusive treatment by superiors, low standard of living, burnout and depression - people tend to lose the capacity for empathizing with others who suffer [9]. According to a recent hypothesis, through cynicism and callousness, the ‘mirror neuron’ effect - the ability to physiologically mimic another’s emotional experience - can diminish [10]. In effect, the individual loses the neurological capacity to physiologically experience what others are feeling.

The effect of diminishing empathy is compounded by the general psychological strain of trauma surgery. Without consistent reinforcement of communication principles, interactive skills tend to regress. In interviews with trauma surgeons nationwide, doctors commonly report feel inadequately prepared to address emotional issues for patients and thus avoid the topic altogether [5]. While the circumstances that curtail communication skills are diverse and multidimensional, ultimately, many of the problems can be resolved by achieving one central goal: applying the primary elements of the doctor-patient relationship into a cohesive model.

## **CREATING A DOCTOR-PATIENT COMMUNICATION MODEL**

After facing severe trauma, patients in need of acute life-saving treatment must encounter a rapid succession of life-saving tests and procedures. Succeeding the initial stage of physical rehabilitation, they must also work to renew the mind and the body. In any situation, when determining the best treatment, doctors need to remember the poignant aphorism: “each illness is unique” [2]. This paradigm for healing extends beyond the restoration that occurs ‘under the scalpel’ and stresses

the importance of emotional mitigation derived from human interaction. Because of the prognostic complexity and diverse patient circumstances, trauma cases present some of the hardest interactions in the medical setting. Accordingly, we will use studies of communication in trauma to frame the most effective model.

## **INTRODUCING THE COMPONENTS OF EFFECTIVE COMMUNICATION**

Before narrowing the focus of our model, we will define the general components of an effective interaction based on previous research into hospital communication. Accounting for the multi-dimensional nature of recuperation, the study, “How does communication heal?” explores both the direct effects of conversation in healthcare - which include comfort and information - in addition to secondary outcomes such as cultivating trust, nurturing agreement and improving self-care. The article evaluates several pathways that emerge from productive communication and lead to measurable, positive outcomes. The authors contend that remedial avenues materialize when clinicians and patients “present and understand one another’s perspectives, find common ground, reconcile differences, achieve consensus on treatment” and when differences cannot be reconciled, “negotiate a mutually acceptable plan” [11]. Based on the study’s themes, the authors’ seven-fold framework can be consolidated into four main categories that will be the main components in our communication model:

- 1) Patient Participation: Educating the patient to make informed decisions.
- 2) Information Flow: Engaging in clinical deliberation by integrating medical logic with patient preference.
- 3) Emotional Regulation: Helping the patient overcome negative emotions.
- 4) Logistical Assistance: Navigating the monetary considerations of the health care system and building a support group to offer assistance, to ensure continuity of care and to prevent abandonment.

Although “Logistical Assistance” is also a category in our framework, the

component does not necessarily have to come from the physician. Therefore, in the following sections, we will just focus on the three determinants directly tied to the doctor: patient participation, information flow and emotional regulation. To refine the focus for our study, we will use the context of trauma rehabilitation.

### PATIENT PARTICIPATION

When dealing with a traumatic event, psychological studies show that patients respond best when the dialogue with their doctor is viewed as a negotiation [12]. When both parties contribute and find common ground, the resulting decision resolves accomplishes a greater variety of goals. In order to deepen our understanding of the effects of the doctor-patient relationship, I conducted an interview with David Magnus, a preeminent leader in bioethics at Stanford University. In his extensive research, Magnus finds that the physician should not spend a majority of the time talking. He advocates the use of the evidence-based “Ask-Tell-Ask” technique, which is a three-fold process: a) Determining the patient’s emotional state and openness to discuss results or treatment; b) Delivering the information in a clear and concise manner; and c) Evaluating the patient’s response to the new information or decision (D. Magnus, personal communication, November 30, 2017). The crux of the “Ask-Tell-Ask” progression is a feedback loop for the physician that helps confirm or refute any preconceptions about the patient’s emotional condition. A medical anthropology review finds that when doctors prevent patient participation and rely on individual instinct or machines, essential diagnostic information is likely to be missed [2].

In our interview, Magnus also described three effective conversational roles for physicians. In the decision process, a doctor can act as a “director” who chooses for the patient, a “facilitator” who addresses differing values and offers treatment options, or merely an “informant” who gives necessary information for the client to decide (Magnus). The communication strategy is about empowering the patient. In a large survey-based study with rehabilitating trauma victims, the authors determine that people who are healing “do not benefit

from the physician’s abdication of power but, rather, from engagement in a process that leads to an agreed management plan” [3]. If patients in the most acute danger are better assisted by active participation, then we should promote involvement for all parties of a medical decision. However, before expecting fertile discussion, a viable relationship needs to be established - one that allows a seamless flow of information and guidance in all aspects of care.

### INFORMATION FLOW AND THE “TRUST” FACTOR

At its core, medicine is characterized by a perpetual circulation of information. Doctors and patients must convey empirical particulars such as test results and physiological responses in addition to normative facts like symptoms and mental state. Applying psychology backgrounds to the clinical setting, a

““ More investigations need to explore the pragmatic effects of specific words in addition to their literal semantic interpretation.

systematic review entitled “The Influence of the Therapist-Patient Alliance” investigates whether techniques that therapists use to reach their clients can be employed to individuals rehabilitating from trauma. The data show that an increased ‘alliance’ score corresponds to vastly improved health, indicated by improved ability to perform tasks for daily living, reduced pain, increased treatment compliance and satisfaction with care [12]. The authors note that in any medical profession, “trust is seen as a global attribute of treatment relationships” and a requisite for successfully exchanging knowledge and counsel [12]. It is evident that trust is a primary determinant in cultivating an effectual information conduit. So how do we augment the level of confidence in the doctor-patient relationship?

In a study on “Trust, social support and patient type,” medical researchers delineate the elements of communication that build a ‘trusting’ relationship and improve outcomes for severely injured patients. For the analysis, the

investigators examine responses from post-trauma patients to the Cologne Patient Questionnaire (CPQ), a standard list of targeted questions to help patients self-assess rehabilitation success. After reviewing the data, the authors propound that “social support” is predicated upon “active listening, how information [is] given and the offer of emotional support” [13]. The literature review adds to previous research by finding that “emotional” and “informational” support are greatest factors in producing trust, accounting for 30-40% of variance in ‘trust’ values [13].

“Informational” support is defined as assisting a patient understand pertinent medical knowledge and skills that relate to the healing process. A physician is expected to clearly state how he or she wants to be understood and to give extensive information to the patient in simple language. When discussing a diagnosis and treatment, doctors need to relay information using common terms and explicitly ask the patient to repeat and explain both the problems and the reasons for the specific action plan. Bioethicist Magnus explains that physicians also need to consider how certain phrases will be interpreted. For instance, by calling an illness or injury “treatable,” patients may assume that they have high chances for recovery; conversely, the doctor may really mean to convey that the problem can be only ‘curtailed’ or ‘delayed.’ By misinterpreting a doctor’s words, a patient can acquire inflated expectations for recovery, leading to diminished satisfaction with treatment in the long-run. Magnus contends that more investigations need to explore the pragmatic effects of specific words in addition to the literal semantic interpretation (Magnus, personal communication). In a review of subjective post-treatment patient surveys, researchers learn that people also value honesty [6]. Trauma poses a wide spectrum of expected outcomes. But by acquiring a realistic impression of their reality, trauma patients can alter their expectations of future physical abilities and correspondingly view their treatment and relative improvement with more positivity. Because of the inherent complication of many medical cases, open and honest information exchange is imperative for any functioning doctor-

patient relationship.

Lastly, in order to adequately absorb the information, an individual must feel that doctor is genuinely investing time in the interaction. Physicians Strathern and Stewart describe the story of a woman who saw her doctor for lower abdominal pain. Upon introduction, the physician told her "I only have seven minutes per patient." With the limited time and rushed atmosphere, the doctor rushed through the consultation and missed an ectopic pregnancy which is fatal in 60% undiagnosed patients. The woman was lucky to survive [2]. The physicians' anecdote refutes the notion that conversations can be artificially reduced for efficiency; each patient needs and deserves sufficient recognition and attention to address every concern.

In terms of "emotional" support, 'trust' is established when physicians inquire not only about physical problems but also "feelings and concerns, understanding of the problem, expectations of therapy and perceptions of how the problem affects function" [3]. Because of its inherently complicated nature, we will now engage in a more thorough review on the idea of empathy and emotional regulation.

### EMOTIONAL REGULATION: CLINICAL EMPATHY AND THE ROLE OF MEDICAL ANTHROPOLOGY

"Clinical empathy" (CE) is an increasingly prevalent focus in medical research addressing a patient's emotional state [14]. Renowned physician Halpern defines CE as "the act of correctly acknowledging the emotional state of another without experiencing that state oneself" [15]. The medical community generally concurs that empathetic communication is elemental to healing. Yet, many researchers doubt that CE is teachable, practical or can be replicated. In response to the lively debate on empathy, many contemporary researchers strive to provide logical structure for CE and to streamline its implementation in conversational instruction.

In a review called "The Role of Empathy," authors Blane, Jani and Mercer delineate a four-step approach to CE that is associated with improved patient outcomes:

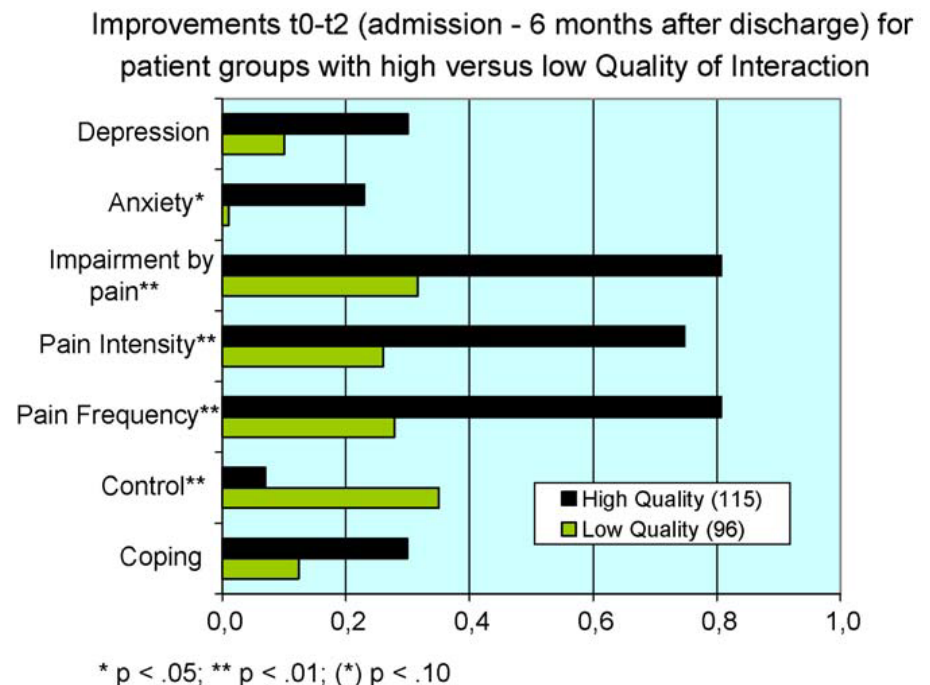
- 1) Emotive: Subjectively sharing another's psychological state;
- 2) Moral: Complying with an intrinsic motivation to help;
- 3) Cognitive: Crafting an objective intervention;
- 4) Behavioral: Executing a communicative response to convey understanding [13].

Of course, many people are not necessarily open to sharing their emotions and feel reluctant to disclose sensitive information to a medical care provider. In this case, clinicians can facilitate the conversation by being clear and honest, "by showing interest in the patient's life, by attentively listening, and by validating patient's expressions of feelings," even if that 'expression' means not relating emotions [11]. Additionally, in life-threatening situations like trauma, "assessing the patient's needs and motivation to survive and recover may be crucial" [13]. Halpern describes an encounter with a dialysis patient who lost the will to live because of a difficult divorce and passed away from non-compliance with her treatment. The doctor reflects that by asking about patient's emotional feelings and distress,

she can better prevent similar tragic misunderstandings [16].

People also utilize a cultural lens when assessing injury and illness. Consequently, every individual will respond to emotional regulation in a drastically different manner. Various circumstances inhibit communication such as differences in speech, social context, contrasting value systems and cultural distrust in medicine. Ultimately, patients will not heal if they disagree with the cause of illness or injury and do not adhere to treatment [1].

To solve the quandaries regarding cultural responses to communication of emotions, the field of medical anthropology develops novel approaches to medical conversation that account for a patient's unique situation. In the medical anthropology textbook, "Curing and Healing," Strathern and Stewart explore a conversational system that addresses these cultural factors. To reconcile dissimilarities of perspective, a physician first needs to establish the breadth or narrowness of knowledge on the patient's condition and ask if his or her stated concerns are being addressed. After clarifying the baseline



**Figure 3.** Graph comparing self-reported 'quality of life' metrics six months post-treatment between patients with 'high' and 'low' level of perceived interaction quality. Data show statistically significant improved scores for pain management, anxiety, and control after discharge for the group with higher interaction quality scores [4].



of information, the next step is to paint a picture of the patient's agency and to determine how it can be enhanced. Does the individual understand how to improve his or her condition? What details will help clarify the reasons for treatment? Strathern and Stewart's pathway accounts for the cultural considerations that affect the enactment of empathic communication, and through a medical anthropology lens, "empathy can more or less be used consciously and with a specific purpose" [17].

Emotional regulation and cultural consideration is an inherently complicated and subjective facet of communication, but its role lies at the core of enhancing a patient's psychological health. A plethora of research is dedicated to adding structure to emotional regulation. For example, an app called "Vital Talk" provides tools, systems and direct language that physicians should utilize in various situations such as giving bad news (Magnus, personal communication). With standardized techniques, doctors can learn to evoke an empathetic disposition and cultivate a fruitful relationship that helps expedite and augment recovery.

### EXPECTED LONG-TERM OUTCOMES OF EFFECTIVE COMMUNICATION

We just delineated the components for a unified model designed to guide physicians towards practicing effective communication. Under our framework for thoughtful, thorough and empathetic conversation, what are the expected outcomes and consequences for the doctor-patient relationship?

In the late 1990s, the medical community issued a consensus statement on physician-patient interaction, declaring that "effective communication between doctor and patient is a central clinical function that cannot be delegated" [3]. For the long-term restorative process, communication significantly influences the perceived results of health care. A medical literature review from 2008 explores the effects of the doctor-patient relationship beyond the preliminary stages of healing, revealing the "importance of interaction quality for the success of rehabilitation" [4]. The researchers

construct an evidence-based questionnaire that appraises the quality of a physician-patient interaction. Consistently, a high 'quality' rating corresponds directly with improved health markers and an enhanced attitude towards remedial progress. (See Figure 3)

Numerous additional studies examine the results of high 'quality' interactions with patients. One long-term report that surveyed trauma patients post-care reveals that better communication from doctors promotes increased patient disclosure - encompassing symptoms, questions and concerns - greater diagnostic accuracy, a higher degree of "satisfaction" and quality of life scores [18]. Although the article and similar studies use subjective 'quality' scores to determine the effectiveness of communication, in future evaluations, our model can serve as the basis for the core components of a productive interaction.

### OUTCOMES OF CLINICAL EMPATHY

In any recovery, but especially traumatic rehabilitation, no factor may be more important than empathy; because of its unique importance, we will now explore the direct outcomes of CE for patients. A 2009 medical review cites a neurophysiology study that correlates CE to amplified activity from a specific nerve cell called 'mirror neurons' that subconsciously mimic another's emotions. In essence, a person can feel joy just by witnessing the emotion [19]. Addressing empathy's clinical utility, a study exploring the "Determinants and patient-reported long-term outcomes of physician empathy" seeks to create an impact model of CE by interviewing patients succeeding invasive treatments. The authors' framework shows that empathetic communication enhances the information flow between doctors and patients, improves long-term psychological health, and helps address every concern [17].

Investigating CE's importance in the "Short and long-term subjective medical treatment outcomes of trauma surgery patients," researchers determine that physician empathy scores - based on a qualitative survey - are the greatest determinant of patient reported outcomes after 12 months [20]. The research method depends on standardized survey-

based scales to calculate "subjective evaluation of medical treatment outcome" (SEMTO). The SEMTO is measured using the CPQ, which asks clients to assess four basic markers of successful rehabilitation: a) Satisfaction with care; b) Treatment effectiveness; c) Quality of life; and d) Reduction in suffering. The self-reported results tend to decline over time because people often do not match their expectations for recovery. However, proper communication curtails the effects because empathy influences "perception of the treatment efficacy, treatment satisfaction, and treatment effect on quality of life" [20]. The results show that even though the medical field is skill-based and empirically-driven, "interpersonal treatment aspects such as emotional care is associated to a more positive evaluation of the medical treatment and its effects" [6]. Empathetic communication has the potential to profoundly augment outcomes in the hospital, and as such, CE warrants special attention for our communication model.

### CONCLUSION

When patients enter the hospital, we want to ensure that they will experience positive outcomes by promoting the best practices from care providers. An experience with trauma or illness launches more than just physical rehabilitation. The restorative process necessitates careful emotional and psychological healing, candid information and a positive yet realistic attitude. Communication is the bridge to reveal a person's true condition, from diagnostic information and patient history to mental health and emotional outlook. Accordingly, in this study, we aimed to enhance the doctor-patient relationship by integrating contributions to conversational practices from various fields into a consolidated communication framework. In our investigation, we focused on trauma cases because they create some of the most complicated situations in the hospital. Through engaging in three main components of effective communication - patient participation, information flow, and emotional regulation - we created a model of best practices for communication that optimizes the health outcomes for rehabilitation patients. (See Figure 4)

Our physician-based framework will help elevate interactions throughout the medical field, and every participant in the healthcare system will benefit from more effective relationships.

Now that we have a unified framework for doctor-patient communication, the next stage of investigation is to determine the optimal manner to teach the model to doctors. In developing a philosophy for communication training, research shows that “90% of what a physician knows comes from experience with patients after the training of formal education” [2]. However, many scholars, including Magnus, still question how to standardize instruction and how to consistently evaluate physicians’ conversational skills. In my interview with the Stanford Medical School curriculum specialist,

I investigated the current forefronts of communication education. The expert remarked that the school seeks to provide experiential learning, encouraging students to learn communication skills in a variety of interactive formats. Initially, medical students study sensitive subjects such as “sex, gender and sexuality” in a traditional lecture setting followed by group discussions over how to approach difficult situations. Prospective doctors also participate in standardized patient tests in which each person is evaluated on a ‘whole picture’ basis to ascertain the physicians’ ability to acquire necessary diagnostic information, tendency to convey empathy, and propensity to help patients understand their condition. The medical school also strives to have students cultivate a longitudinal relationship with

an individual. Accordingly, they are matched with real patients in a clinic to assess and treat over time. Stanford Medical School is currently attempting to add earlier clinical experience for students to practice genuine interactions before relying on medical knowledge to carry a conversation (M. Sow, personal communication, November 27, 2017). As we continue to improve the learning environment, the Stanford Medical School curriculum stands as a salient example of how to instruct interactive techniques.

Hopefully, with the common model for communication presented in our research, we can effectively emphasize the doctor-patient relationship in education and advance the physical and psychological outcome for manifold patients. ■

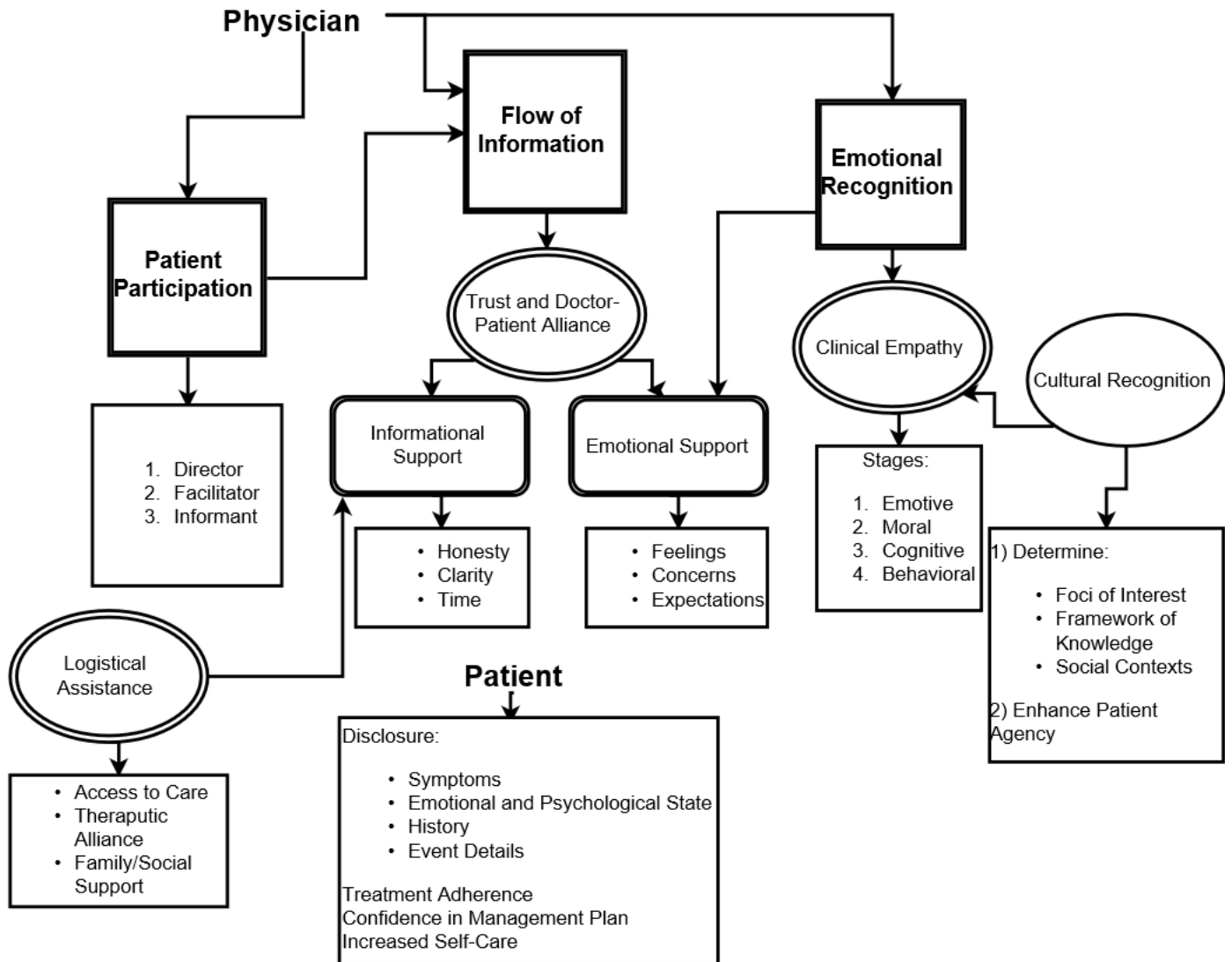


Figure 4. Original flow chart model for doctor-patient communication based on synthesized research.

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Avi Kaye is a freshman at Stanford University from Denver, Colorado studying to become a doctor. In his undergraduate experience, Avi is pursuing an interdisciplinary approach to education, which, in the future, will help him address both the physical and humanistic aspects of healing as a physician. For his academic focus, he is interested in exploring the effects of psychological and social conditions on individuals' physiological therapeutic process. Avi is also a certified Emergency Medical Technician, serving as a member of a student EMT group and assisting as a teaching assistant for Stanford's EMT course. Avi dedicates his research to his brother who miraculously survived and recovered from a horrific motor vehicle accident in February of 2017.

# Impact of Carbon Tax Policies on the Global Agricultural Economy: A Computational Spatial Partial Equilibrium Modeling Approach

MARY ZHU, STANFORD UNIVERSITY

Developed amid the Paris Agreement controversy, this model projects the environmental and economic impacts of carbon tax policies from 2012 to 2050. Simulating the Climate Protection and Justice Act of 2015 (CPJA) as an example, the model projects the impacts on the global agricultural market under three scenarios: i) Status Quo, with no country adopting the CPJA, ii) CPJA Developed, adopted by major developed countries, iii) CPJA World, adopted by all countries.

The linear programming model optimizes an objective function (social welfare) subject to constraints across 11 commodities and 17 countries/regions. Implemented with the BPMPD solver and Microsoft VBA (free/home software), the model in the static phase completes a comparative analysis of the scenarios' trade-offs; in the dynamic phase, it generates iterative projections of their impacts.

Validated with up to 83% accuracy, the results show that under CPJA Developed, although developing countries suffer potential carbon leakage and developed countries decline in production and exports, 5.5 billion tons of carbon are reduced. Under CPJA World, all countries experience a share of the rising prices and decreased trade/production while 15.5 billion tons of carbon are reduced. With global cooperation, the world will benefit environmentally and more evenly share the economic burden.

## INTRODUCTION

Although the threat of global warming has long been recognized, climate change regulation remains a contentious political topic. Despite contributing to 16% of global emissions, the U.S. failed to join the 1997 Kyoto Protocol, an international climate agreement that placed strict reduction targets on industrialized nations [1][2]. Now, based on promises made in early 2016 by President Donald Trump, the U.S. is considering withdrawal from the Paris Agreement, a global plan to limit the increase in world temperatures to less than 2 degrees Celsius above pre-industrial levels [3]. Without participation from the U.S. as the world's second greatest emitter, other countries are less likely to remain in the Agreement, jeopardizing the international effort altogether [4].

Since the start of the recent election, global warming has been relentlessly debated. When Senator Bernie Sanders openly endorsed carbon pollution taxes during his U.S. Presidential campaign,

climate change was instantly thrust in the political spotlight. Citing changing temperatures as the greatest threat to national security, Sanders proposed the Climate Protection and Justice Act (CPJA) of 2015 on December 10 [5]. This was one day before the close of the UN's 21st annual Conference of the Parties (COP21), a meeting of over 190 national leaders that created the Paris Agreement [6]. If passed, the CPJA would tax \$15 per metric ton of carbon pollution starting in 2017 and eventually charge \$150 per metric ton by 2050, purportedly reducing carbon pollution levels to 80% below those of 1990 [7].

Yet, according to a national survey by Duke University, only 29% of Americans strongly support or somewhat support a carbon tax [8]. Concerns about weakening U.S. economic competitiveness and energy-intensive American companies relocating to less-regulated areas (called carbon leakage) have hindered the carbon regulation effort [9] [10]. Furthermore, previous attempts at implementing carbon taxes revealed serious problems or resulted

in failures. In 2012, Australia's carbon tax was abolished only two years later after household electricity prices and unemployment rose 20% and 10%, respectively [11][12]. Meanwhile, British Columbia's current carbon tax merely spurred consumers to purchase gas elsewhere, resulting in a 136% spike in Canadian vehicle crossings over the Washington state border [11].

Because environmental movements tend to focus more on the regulation of natural gas, oil, electricity, or industry sectors, the carbon footprint of agriculture is often overlooked. Yet, the global livestock industry produces more emissions than all cars, planes, trains, and ships combined, accounting for almost one third of the world's greenhouse gas (GHG) emissions [13] [14].

However, during the pre-budget consultation process of British Columbia's carbon tax, industry leaders claimed that agriculture would be "one of the hardest-hit industries" [15]. With the U.S. as one of the world's top agricultural producing and exporting

countries, the consequences of a carbon tax on U.S. trade competitiveness could be drastic [16]. Yet, with a global temperature forecasted to rise up to 10 degrees Fahrenheit in the next century, the resulting increase in the severity of droughts, hurricanes, and other extreme weather events could be several times more devastating [17].

Although carbon taxes have already been implemented in several countries, including Ireland, Australia, and the UK, and have even garnered the support of Exxon Mobil, the world's largest publicly traded oil company, they are still strongly opposed by a sizable segment of the U.S. [18][19]. Consequently, after Sanders's CPJA of 2015 was referred to the Committee on Finance in the U.S. Senate, it ended up dying in the 114th Congress because it was never enacted [20]. However, at this time, an analysis of the environmental and economic trade-offs of such a carbon tax would provide valuable insight and assist federal policymakers in making the most informed decisions possible. Although the model developed in this study can simulate any carbon tax plan, the CPJA is used simply as an example.

This study introduces a novel spatial partial equilibrium model that analyzes the following three scenarios and their impacts on U.S. competitiveness and the environment between the years 2012 and 2050:

- i. Status Quo: no country adopting the CPJA
- ii. CPJA Developed: only the major developed countries studied adopting the CPJA
- iii. CPJA World: all the countries of the world adopting the CPJA

**LITERATURE REVIEW**

Several studies conducted previously have investigated similar issues, albeit using different methodologies. Schneider & McCarl used the programming-based Agricultural Sector and Mitigation of Greenhouse Gas model to simulate "farm sector response to increased energy prices" [21]. However, the study applied a complex multi-purpose generic model with an unnecessary focus on minor details, such as numerous individual

U.S. regions, and only analyzed 8 major commodities when simulating trade relationships. Rivers and Schaufele used a dataset covering the interprovincial and international trade of Canadian food commodities to measure the impact of the 2008 British Columbian carbon tax on world agricultural trade [22]. However, the study was based purely on aggregate agricultural commodities data and covered a relatively short period of four years (2008-2011). Elliot et al. investigated the impacts of countries adopting different carbon tax policies on world trade using an open-source Computable General Equilibrium model, CIM-EARTH [23]. However, the predictions were reported for the year 2020 only, countries were aggregated into generalized groups, and the model was not tested for historical validity. In a study conducted by the Australian Farm Institute, the economic impacts of Australia's Carbon Pollution Reduction Scheme were projected using static farm-level financial modelling [24]. It analyzed the costs of the studied policy on individual farms and concluded that farm cash margins could decline by up to 18% by 2020 due to indirect impacts. However, this study did not include any changes in the combination of farm inputs as a result of changes in price, failing to forecast "actual farm business outcomes" [25][26]. Finally, Zhao used a gravity model improved with carbon tax policy variables and data from OECD countries and various industries to project the impact of carbon taxes on the global competitiveness of energy-intensive industries [27]. The results

revealed a statistically significant negative effect, especially on non-resource-based industries.

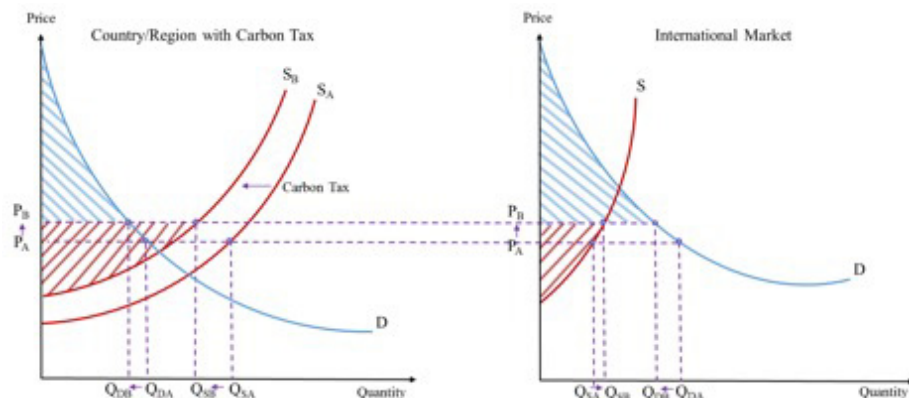
However, few studies have yet built from scratch a computational model that can simultaneously 1) compare carbon tax policies from a comprehensive economic and environmental perspective, 2) project long-term in addition to short-term implications, 3) consider individual in addition to global impacts, and 4) do so through a purely objective and quantitative analysis.

**METHODOLOGY**

**THEORETICAL MODEL**

The global agricultural market is highly integrated among countries/regions due to international trade. A price or demand/supply change of one product in one country will affect the prices and demand/supply of multiple products in other countries.

Figure 1 depicts the impacts of a carbon tax adopted by one country/region on national and global agricultural supply and demand. Assume that a single food commodity is traded between a country/region and the international market. If a country/region adopts a carbon tax, *ceteris paribus*, the marginal cost of producing the commodity will increase, decreasing overall domestic production of the commodity and shifting the domestic supply curve to the left. Consequently, the world price of the commodity increases from  $P_A$  to  $P_B$  and the country/region that is taxed experiences decreases in the quantity supplied ( $Q_{SA}$



**Figure 1.** Impact of a carbon tax adopted by one country/region on domestic and global markets.

to  $Q_{SB}$ ), quantity demanded ( $Q_{DA}$  to  $Q_{DB}$ ), quantity exported ( $Q_{SA} - Q_{DA}$  to  $Q_{SB} - Q_{DB}$ ), and consumer surplus (the difference between consumers' willingness to pay and the market price, represented by the upper dashed region). However, a carbon tax may have an ambiguous effect on producer surplus (the difference between producers' willingness to sell and market price, represented by the lower dashed region) depending on the relative changes in production and price. Meanwhile, the international market experiences an increase in quantity supplied ( $Q_{SA}$  to  $Q_{SB}$ ) and producer surplus, and decreases in the quantity demanded ( $Q_{DA}$  to  $Q_{DB}$ ), quantity imported from the region/country adopting the tax ( $Q_{DA} - Q_{SA}$  to  $Q_{DB} - Q_{SB}$ ), and consumer surplus. This partial equilibrium model mimics the reactions of parties in the global agricultural market for each commodity studied.

## STATIC MODEL

The spatial equilibrium in each time period is based on Samuelson's theory that the equilibrium results from maximizing total social welfare across all commodities and countries [28]. Such spatial partial equilibrium models are generic frameworks, and can be applied to different economic sectors, such as forestry [29].

## OBJECTIVE FUNCTION

The objective function, based on Buongiorno et al., maximizes the total social welfare across all food groups and countries/regions [29]. The total social welfare is calculated as the sum of consumption values minus the sum of production values (the area under the demand curve minus the area under the supply curve) minus the total transportation cost among countries.

$$\max W = \sum_i \sum_m \int_0^{D_m} P_{im}(D_{im}) dD_{im} - \sum_i \sum_m \int_0^{S_m} P_{im}(S_{im}) dS_{im} - \sum_i \sum_j \sum_m r_{ijm} T_{ijm} \quad [1]$$

where  $W$  = total social welfare,  $i$  and  $j$  = countries,  $m$  = commodity,  $D_{im}$  = commodity  $m$  consumed in country  $i$ ,  $S_{im}$  = commodity  $m$  supplied in country  $i$ ,  $T_{ijm}$  = commodity  $m$  traded between countries  $i$  and  $j$ ,  $P_{im}$  = price

of commodity  $m$  in country  $i$ . and  $r_{ijm}$  = transportation cost of commodity  $m$  between countries  $i$  and  $j$ . The demand price (constant 2012 USD)  $P(D)$  = the inverse demand function, and supply price  $P(S)$  = the inverse supply function, and both  $D_{im}$  and  $S_{im}$  are equilibrium quantities, where quantity supplied equals quantity demanded.

The demand equation, based on Buongiorno et al. [29], over periods is:

$$\frac{D_m}{D_m^\#} = \left( \frac{P_m}{P_{m,-1}} \right)^{\alpha_m} \quad [2]$$

where  $P_{-j}$  = the previous period's price,  $D^\#$  = current demand at the previous period's price, and  $\alpha$  = price elasticity of demand. The demand ratio and price ratio are associated via price elasticities.

The supply equation, based on Buongiorno et al. [29], over periods is:

$$\frac{S_m}{S_m^\#} = \left( \frac{P_m}{P_{m,-1}} \right)^{\beta_m} \quad [3]$$

where  $S^\#$  = current supply at the previous period's price, and  $\beta$  = price elasticity of supply.

The above calculation can be simplified with a linear approximation as described below using the demand equation as an example. With a constant elasticity, the inverse demand equation of [2] can be approximated by the tangent at the point  $(D^\#, P_{-j})$ , where there are small changes in price and quantity:

$$\begin{aligned} P &= a + bD \\ a &= P_{-1} - bD^\# \\ b &= \frac{P_{-1}}{\alpha D^\#} \\ W &= aD + \frac{1}{2} bD^2 \end{aligned} \quad [4]$$

The consumption and production values in [1] can each be approximated as the integral of the local linear approximation in [4] as a quadratic formulation of  $W$ .

## ECONOMIC CONSTRAINTS

Equation [5] is the material balance constraint, which implies that the demand plus the export should equal the supply plus the import of each commodity.

$$D_{im} + \sum_j T_{ijm} = \sum_j T_{jim} + S_{im} \quad \forall i, m \quad [5]$$

where  $D_{im}/S_{im}$  = commodity demanded/supplied in each country  $i$  for commodity  $m$ , and  $T_{ijm}$  = shipment of commodity  $m$  from country  $i$  to country  $j$ .

Over the years, the trade flow changes between two countries have some lagging characteristics, per Buongiorno et al. [29]; that is, it takes time to adjust the trade flows to reflect various changes that affect the quantities traded.

$$T_{ijm}^- \leq T_{ijm} \leq T_{ijm}^+ \quad \forall i, j, m \quad [6]$$

where the superscripts - and + refer to a lower bound and upper bound respectively.

The carbon footprint per commodity captures its entire lifecycle, from production to retail distribution. In terms of carbon taxation, the ratios between GHG emitted during the agricultural and manufacturing phases are calculated by Jelínková et al. [30]. Since the CPJA defines a "carbon polluting substance" as "coal (including lignite and peat), petroleum, and any petroleum product, or natural gas" that will release GHG upon combustion, only the carbon pollution released during the manufacturing phase will be taxed [31]. The ratios excluded by Jelínková et al. are estimated as 0.1 based on the average presented by the EPA [1]. The food wastage, blue water, or land use footprints may also be calculated with this model.

The set of equations [7] reflects the carbon, food wastage, blue water, or land use footprints produced.

## ENVIRONMENTAL CONSTRAINTS/FOOTPRINTS

The carbon footprint per commodity captures its entire lifecycle, from

production to retail distribution. In terms of carbon taxation, the ratios between GHG emitted during the agricultural and manufacturing phases are calculated by Jelínková et al. [30]. Since the CPJA defines a “carbon polluting substance” as “coal (including lignite and peat), petroleum, and any petroleum product, or natural gas” that will release GHG upon combustion, only the carbon pollution released during the manufacturing phase will be taxed [31]. The ratios excluded by Jelínková et al. are estimated as 0.1 based on the average presented by the EPA [1]. The food wastage, blue water, or land use footprints may also be calculated with this model.

The set of equations [7] reflects the carbon, food wastage, blue water, or land use footprints produced.

$$\sum_m f_{mn} S_m + \sum_m g_{mn} D_m \leq F_n^+ \quad \forall n \tag{7}$$

where  $n$  = environmental considerations,  $f_{mn}/g_{mn}$  = produced carbon pollution (MT) or food wastage (MT) or blue water (CUM) or land use (ha) per unit of  $m$  produced/consumed and  $F_n^+$  = maximum carbon pollution (MT) or food wastage (MT) or blue water (CUM) or land use (ha) allowed in each country.

**DYNAMIC MODEL**

The dynamic phase of the model represents the supply and demand shifts over time due to carbon policies and economic growth.

With the implementation of carbon taxes, the upward shift of the linear approximation of the inverse food supply of a country is modeled as:

$$P = a + bS + c(t - t_{-1}) \tag{8}$$

where  $a$  and  $b$  are the same as defined in [4],  $S$  = quantity supplied at price  $P$ ,  $c$  = carbon generated per unit of quantity supplied, and  $t$  = tax rate for generated carbon (USD/MT).

With the economic and population growth, the periodic food demand shifts as:

$$D = D_{-1}(1 + \alpha g) \tag{9}$$

where  $D$  = food demand,  $g$  = rate of annual GDP growth, and  $\alpha$  = elasticity of demand with respect to GDP.

Per Trade Gravity theory [32], the trade flow growth between two countries is mainly driven by their GDP growth rates, so the periodic trade lagging bounds shift as:

$$\begin{aligned} T^- &= T_{-1}(1 + e_x g_x + e_i g_i - \varepsilon) \\ T^+ &= T_{-1}(1 + e_x g_x + e_i g_i + \varepsilon) \end{aligned} \tag{10}$$

where  $e_x$  = elasticity of trade flow with respect to exporter GDP growth,  $g_x$  = growth rate of exporter GDP,  $e_i$  = elasticity of trade flow with respect to importer GDP growth,  $g_i$  = growth rate of importer GDP,  $\varepsilon$  = maximum deviation of trade flow from the trend.

**MODEL SCOPE**

Table 1 lists the countries/regions and commodities studied. Countries/regions were selected based on their contributions to the global agricultural market in terms of production and trade. Commodities were selected based on the FAO’s Food Outlook [33], in addition to others.

**MODEL IMPLEMENTATION**

The model used in this study is implemented with an interior point convex quadratic solver (BPMPD) [34] and Microsoft Visual Basic for Applications (VBA). BPMPD is a generic solver for optimization problems. It is similar to Excel Solver but much more powerful when solving large problems (Excel Solver cannot handle the problem size for this model). The model parameters are recorded on Microsoft Excel spreadsheets, while the optimization problem itself is solved using BPMPD. A Mathematical Programming System (MPS) file is generated with a VBA program from Excel spreadsheets and the BPMPD solver is invoked in the command line, after which the results in a text file are loaded to Excel. The VBA program automates projections by updating the model parameters from period to period based on scenario assumptions like GDP growth rates and others, and saving the results across periods of time. The model parameters for the three scenarios are saved to different spreadsheets and can be copied to the staging area (Model sheet)

programmatically. The results reported in this study can be reproduced with the model at any time, while new results with different assumptions and parameters can also be obtained easily.

The next section “Program Interfaces” lists the functions of major modules written in the VBA programming language.

```

Program Interfaces (Visual Basic for Applications)
'Reset Model/Parameters sheets based on Base sheet; clear Results sheet
'Copy all base model parameters from Base sheet to Parameters sheet
'Reset decision variables on Model sheet based on Parameters sheet
'Clear Results sheet
Sub Reset()

'Generate MPS sheet based on data from Model and Parameters sheets
'Save MPS sheet as a formatted text file
'Call BPMPD solver to solve model in MPS file and save solution in another file
'Get results of the decision variables from solution file
>Delete MPS solution files
Sub RunSolver()

'Copy results from Model sheet to Results sheet
Sub Record()

'Update Parameters sheet based on specified changes in corresponding scenario sheet
    
```

Country/Region		Commodity	
Code	Name	Code	Name
AU	Australia	10	Bovine Meat
BR	Brazil	11	Pigmeat
CA	Canada	12	Poultry Meat
CN	China	13	Dairy
EU	European Union	14	Wheat
ID	Indonesia	15	Coarse
IN	India	16	Rice
JP	Japan	17	Oilseeds
KR	Republic of Korea	18	Fruits
MX	Mexico	19	Vegetables
NZ	New Zealand	20	Aquaculture
RU	Russian Federation		
TH	Thailand		
TR	Turkey		
US	United States		
ZA	South Africa		
ZY	Rest of World		

**Table 1.** Countries or regions and commodities studied.

```

'For example, original parameter a
has value a0 and annual change is c
'There are three types of changes
over specified period (start_year ~
end_year):
'1) v_change (value change): a =
a0 + c * (end_year - start_year
+ 1)
'2) v_new (new parameter value):
a = c
'3) r_change (rate change): a =
a0 * (1+c)^(end_year - start_year
+ 1)
Sub Update ()

'Copy then sort results for
charting purposes
Sub SortResults ()

'Aggregate results for charting
purposes
Sub SumSortResults ()

'Make projection to specified end
year from base year
'Before making projection:
'1) call Reset () to reset various
sheets and clear old results
'Loop through each period:
'1) call RunSolver() to solve
optimization problem
'2) call Record() to store results
'3) call Update() to update model
for next iteration
'After looping through all periods:
'1) call SortResults() to sort
results for reporting
'2) call SumSortResults() to
aggregate results for reporting
Sub Project ()

```

## MODEL VALIDATION

Equation [11] measures the average of the absolute relative differences

between projected values and actual values across total observations from 1993 to 2012 to assess the accuracy of the model's projections.

$$\varepsilon = \frac{\sum_k \left| \frac{Y_k - A_k}{A_k} \right|}{N} \quad [12]$$

where  $\varepsilon$  = Average Absolute Relative Error (AARE),  $Y$  = projected value at point  $k$ ,  $A$  = actual value at point  $k$ , and  $N$  = total observations.

## ESTIMATIONS AND ASSUMPTIONS

### MODEL PARAMETERS

Table 2 summarizes the average economic and environmental effects of 1 metric ton of each commodity. Estimates of demand price, income, and supply price elasticity per commodity differ for each country. Due to the interest of space, only the economic parameters for the U.S. are displayed in Table 2. All economic parameters are derived from the U.S. [35][36][37][38][39][40] with the assimilation of the food groups into the commodities studied in this research. Estimates of carbon pollution, blue water, land use, and food waste ratio data are held constant across all countries and are similarly derived from previous studies [41][42][43][44]. The

ratio of taxable energy-related GHG is estimated from Jelínková et al. [30] and EPA [1].

### MODEL VALIDATION WITH HISTORICAL DATA

The model is validated with equation [11] using the above listed parameters and actual production, consumption, import, export, and export value data from 1993 to 2012 derived from the FAOSTAT Database [16]. Transportation costs for each commodity are estimated to be 10% of the world export unit value (aggregate world export value divided by aggregate world export quantity). For simplicity, this model does not deal with bilateral trade; instead, all countries export and import to a common "world market."

Table 3 shows that the model projects the world consumption, production, import, export, and price of the commodities with at least 79 ~ 83% accuracy. The potential margin of error for individual countries/regions is greater because their specific choices are more volatile over the years.

### ASSUMPTIONS FOR THE SCENARIOS

The following table outlines the design of Bernie Sanders's Climate Protection and Justice Act of 2015.

Table 5 identifies which countries

Parameter	Beef	Pork	Poultry	Dairy	Wheat	Grain	Rice	Oils	Fruit	Veg.	Aqua	
Economic Parameters (US as an example)	Demand price elasticity	-0.5	-0.5	-0.5	-0.52	-0.25	-0.25	-0.25	-0.27	-0.37	-0.37	-0.41
	Income elasticity	0.68	0.68	0.68	0.71	0.34	0.34	0.34	0.37	0.51	0.51	0.56
	Supply price elasticity	0.55	0.9	0.8	0.41	0.5	0.55	0.35	0.35	0.94	0.87	0.47
Environmental Parameters (per metric ton of commodity) (World)	CO2 (MT)	68.8	7.9	5.4	2.1	1	2.2	3.9	2.55	0.9	1.6	3.24
	Ratio energy-related GHG	0.5	0.51	0.1	0.52	0.5	0.51	0.5	0.1	0.58	0.61	0.1
	Blue Water (CUM)	15.42	5.99	4.33	3.29	2.01	1.64	3.4	2.36	0.96	0.32	2.18
	Land (ha)	17.22	5.44	4.85	0.85	0.36	0.36	0.36	0.67	0.12	0.08	0.23
Ratio of food wasted	0.15	0.15	0.15	0.14	0.1	0.1	0.1	0.05	0.24	0.24	0.08	

Table 2. Economic and environmental footprint parameters

	Consumption	Production	Imports	Exports	Price
Country/Region	0.28	0.3	1.91	3.6	0.22
World	0.17	0.17	0.21	0.21	0.21

Table 3. Model validation with Average Absolute Relative Error (AARE) between historical and projected data of countries/regions and the world.



adopt the CPJA in each scenario. Under the Status Quo, no countries adopt the policy. Under CPJA Developed, all major developed countries/regions studied enforce the policy. Under CPJA World, all countries/regions adopt the policy.

Table 6 lists the assumed annual GDP growth rates used in the dynamic phase of the model to project the consumption, production, imports, exports, and prices of the commodities per country from 2012 to 2050. Values and estimates are based on projected GDP data provided by the Organisation for Economic Co-operation and Development [45].

**RESULTS**

The results reveal the projected impacts of the CPJA on the production, imports, exports, consumption and production value, price, carbon emissions, blue water usage, land use,

and food wastage of 11 commodities on 17 countries/regions and the world. Due to the interest of space, besides the overall agriculture product, only bovine meat is presented in this section because it maintains the greatest ratio of the size of the carbon tax to the price of the commodity; thus, it is impacted most substantially by the CPJA. Other commodities show similar impact patterns but with less significance. Similarly, besides aggregated country groups, this section only compares corresponding U.S. commodity markets with those of the greatest producing country's.

**IMPACT ON BOVINE MEAT MARKETS**

Since bovine meat generates the most carbon pollution per metric ton of product as shown in Table 2, this market is impacted the most heavily

by the CPJA. Under the Status Quo, the U.S. and Brazil both produce large quantities while maintaining low prices (Figure 3). However, under CPJA Developed, Brazil's (a developing country's) production and prices remain similar to Status Quo levels, while U.S. (a developed country's) production decreases and domestic prices and imports rise dramatically. Under CPJA World, while production in both the U.S. and Brazil decreases and prices rise, imports also remain low.

Since developing countries are free to produce at no cost in the absence of carbon taxes under CPJA Developed, developed countries experience severe declines in competitiveness as production and exports decrease, and prices and imports rise dramatically (Table 7). However, when both developed and developing countries are subject to taxes under CPJA World, both

Fee year	Fee rate (USD/MT)	Policy description
2017	15	From 2017, the rate starts at 15 USD per metric ton of carbon emitted.
2035	73	From 2017 to 2035, the tax rate increases annually by 3.22 USD per metric ton of carbon emitted.
2050	150	From 2036 to 2050, the tax rate increases annually by 5% per metric ton of carbon emitted, adjusted for inflation.

Table 4. CPJA annual tax rate per metric ton of carbon emitted by carbon polluting substances.

Year	AU	BR	CA	CN	EU	ID	IN	JP	KR	NZ	RU	TH	TR	US	ZA	ZY	
2013-2015	2.6	2.1	2.4	7.5	0.8	5.9	5.1	1.3	3.7	2.9	3.1	3.3	3.4	3.6	2.7	2.5	3.4
2016	3.7	2.7	2	5.8	2	5.8	6	0.8	3.3	2.8	2.4	2.8	3.2	5.6	2.9	5.4	3.2
2017	3.7	2.7	2	5.8	2	5.8	6	0.8	3.3	2.8	2.4	2.8	3.2	5.6	2.9	5.4	3.2
2018	3.7	2.7	2	5.8	2	5.8	6	0.8	3.3	2.8	2.4	2.8	3.2	5.6	2.9	5.4	3.2
2019-2020	3.7	2.7	2	5.8	2	5.8	6	0.8	3.3	2.8	2.4	2.8	3.2	5.6	2.9	5.4	3.2
2021-2025	3.3	2.5	2.1	4.4	1.9	5.5	5.9	1.1	2.8	2.8	2.6	2.7	3	4.2	2.4	4.9	3
2026-2030	3.1	2.7	2.1	3.6	1.9	5	5.8	1.3	2.4	3.1	2.5	2.2	2.8	3.8	2.4	4.5	2.8
2031-2035	2.9	2.7	2	3.4	1.7	4.4	5.4	1.3	2	3.5	2.4	1.1	2.6	3.3	2.1	3.9	2.6
2036-2040	2.6	2.4	1.9	3.2	1.6	4	4.9	1.1	1.8	3.6	2.3	0.3	2.3	2.8	1.9	3.2	2.3
2041-2045	2.4	2.3	1.9	2.6	1.4	3.8	4.4	1	1.6	3.5	2.2	0.6	2.1	2.3	1.7	2.6	2.1
2046-2050	2.3	2.2	1.9	2	1.4	3.7	4	1.1	1.5	3.2	2.2	1.8	2	1.9	1.6	2.2	2

Table 6. GDP annual growth rate (%) by country/region.

Scenario	AU	BR	CA	CN	EU	ID	IN	JP	KR	MX	NZ	RU	TH	TR	US	ZA	ZY
Status Quo																	
CPJA Developed																	
CPJA World																	
CO2 (MT)	68.8	7.9	5.4	2.1	1	2.2	3.9	2.55	0.9	1.6	3.24						
Ratio energy-related GHG	0.5	0.51	0.1	0.52	0.5	0.51	0.5	0.1	0.58	0.61	0.1						
Blue Water (CUM)	15.42	5.99	4.33	3.29	2.01	1.64	3.4	2.36	0.96	0.32	2.18						
Land (ha)	17.22	5.44	4.85	0.85	0.36	0.36	0.36	0.67	0.12	0.08	0.23						
Ratio of food wasted	0.15	0.15	0.15	0.14	0.1	0.1	0.1	0.05	0.24	0.24	0.08						

Table 5. Countries adopting the CPJA in each scenario.

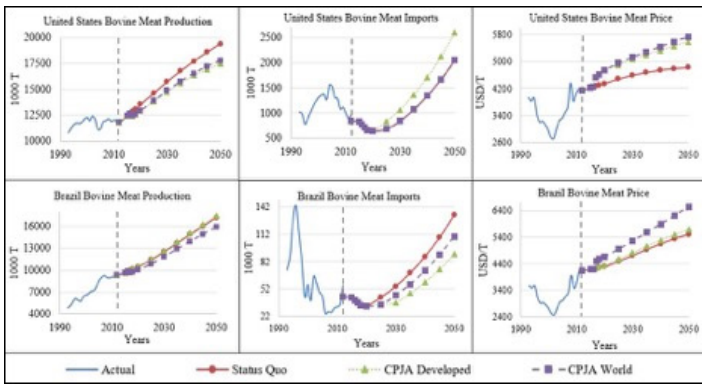


Figure 3. Impact of CPJA on the United States and Brazil bovine meat markets

Economic Indicator	Actual 2012	Status Quo 2050	CPJA Developed 2050	CPJA World Δ %	2050	Δ %
<b>United States</b>						
Production (1000T)	11801	19414	17472	-10	17774	-8.5
Import (1000T)	844	2050	2608	27.2	2053	0.2
Export (1000T)	998	2585	2587	0.1	2587	0.1
Price (USD/T)	4141	4827	5589	15.8	5746	19
<b>Developed Countries</b>						
Production (1000T)	26443	43985	39000	-11.3	40402	-8.1
Import (1000T)	5331	10415	12646	21.4	10826	4
Export (1000T)	5804	16156	15354	-5	15778	-2.3
Price (USD/T)	4214	4854	5431	11.9	5741	18.3
<b>Developing Countries</b>						
Production (1000T)	40662	78220	79642	1.8	73340	-6.2
Import (1000T)	4538	17467	14998	-14.1	16515	-5.5
Export (1000T)	4064	11727	12290	4.8	11562	-1.4
Price (USD/T)	4436	5240	5445	3.9	5988	14.3
<b>World</b>						
Production (1000T)	67105	122205	118643	-2.9	113743	-6.9
Import (1000T)	9869	27882	27644	-0.9	27341	-1.9
Export (1000T)	9869	27882	27644	-0.9	27341	-1.9
Price (USD/T)	4350	5119	5441	6.3	5911	15.5

Table 7. Bovine meat production, trade, and price in 2050.

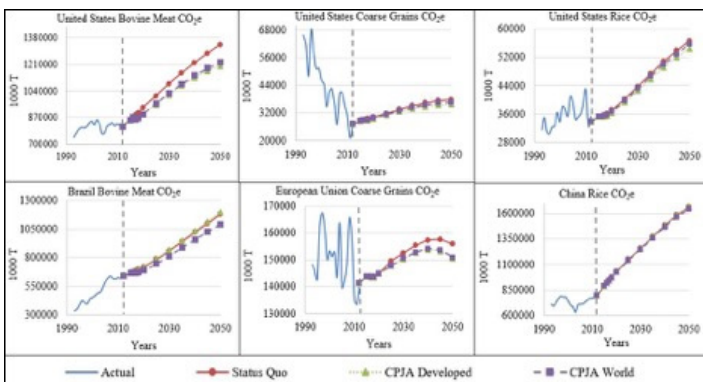


Figure 4. Impact of CPJA on the United States and Brazil bovine meat markets

Economic Indicator	Actual 2012	Status Quo 2050	CPJA Developed 2050	CPJA World Δ %	2050	Δ %
<b>United States</b>						
Consumption value	437	718	727	1.3	732	1.9
Production value	549	1107	1111	0.3	1125	1.6
Import value	33	99	107	8.9	102	3.3
Export value	146	488	491	0.6	496	1.6
<b>Developed Countries</b>						
Consumption value	1981	2369	2395	1.1	2410	1.7
Production value	2231	3387	3394	0.2	3442	1.6
Import value	391	707	738	4.5	728	3
Export value	641	1725	1737	0.7	1760	2
<b>Developing Countries</b>						
Consumption value	5179	9319	9337	0.2	9456	1.5
Production value	4930	8300	8338	0.5	8424	1.5
Import value	602	1210	1193	-1.4	1230	1.7
Export value	353	192	194	1.1	198	3.4
<b>World</b>						
Consumption value	7161	11688	11731	0.4	11866	1.5
Production value	7161	11688	11731	0.4	11866	1.5
Import value	994	1916	1931	0.8	1958	2.2
Export value	994	1916	1931	0.8	1958	2.2

Table 8. Overall economic impacts of the CPJA (billion USD).

Country/Region	Actual 2012	Status Quo 2050	CPJA Developed 2050	CPJA World Δ %	2050	Δ %
United States	1.51	2.62	2.47	-5.7	2.5	-4.6
Developed Countries	4.08	6.59	6.19	-6	6.31	-4.2
Developing Countries	10.4	21.37	21.49	0.6	20.85	-2.4
World	14.48	27.95	27.68	-1	27.16	-2.8
Export value	146	488	491	0.6	496	1.6

Table 9. Projected carbon pollution in 2050 (billion metric tons).

Scenario	United States	Developed	Developing	World
CPJA Developed	-3	-7.8	2.3	-5.5
CPJA World	-2.5	-5.6	-10	-15.5

Table 10. Accumulated carbon pollution changes from Status Quo, 2012 to 2050 (billion metric tons).

have decreasing production and rising prices. Thus, while developed countries still bear more of the tax burden under CPJA World, the economies of all countries and global trade decline more evenly throughout, but less severely for developed regions relative to CPJA Developed.

### IMPACTS ON OVERALL AGRICULTURE MARKETS

Since the commodities are inelastic, implementing the CPJA increases prices more than it decreases production and consumption, resulting in increased consumer and producer surpluses due to increased consumption and production values for all areas under CPJA Developed and CPJA World (Table 8).

### IMPACT ON CARBON POLLUTION

The CPJA produces the largest decline of pollution in bovine meat markets relative to the other commodity markets because bovine meat has the greatest carbon intensity (Table 2, Figure 4).

Table 9 shows that in 2050, although GHG appears to decline most drastically for developed countries under CPJA Developed (-6.0%), energy-intensive industries may actually be transferring production to unregulated developing countries, which experience a 0.6% increase. Thus, although developed countries appear to be reducing less carbon under CPJA World (-4.2% as opposed to -6.0%), global carbon emissions decline more significantly (-2.8% as opposed to -1.0%) because those carbon-intensive industries have no unregulated areas to relocate to.

Developing countries experience a cumulative 2.3 billion MT pollution increase under CPJA Developed due to potential carbon leakage (Table 10). However, 15.5 billion MT pollution are reduced under CPJA World as opposed to a 5.5 billion MT reduction under CPJA Developed.

## CONCLUSION AND DISCUSSION

This study effectively captures the ongoing controversy regarding the impacts of carbon taxes on the global

agricultural market. Under CPJA Developed, the U.S. and other developed countries are harmed economically, while developing countries are damaged by potential carbon leakage. However, when all countries are subject to the same carbon tax under CPJA World, they are all negatively impacted by increased prices and decreased trade and production (albeit, for developed countries, less severely than under CPJA Developed). As a result, domestic consumers are harmed and Trump's concerns about the U.S. economy and his potential decision to withdraw from the Paris Agreement may have some merit. However, with substantially less carbon pollution and more revenue generated by domestic producers under a carbon tax, it is difficult to determine whether lower food prices (and all price levels in general, as the CPJA would impact energy-related emissions beyond just agriculture) are worth more than a cleaner environment.

Based on the results, price increases induced by carbon taxes outweigh production decreases, confirming Schneider & McCarl's findings that "through market price adjustments... costs are largely passed onto consumers" [46]. Further, as similarly concluded by previous studies [47][48][49], the economic consequences of carbon taxes become less significant to national and global agricultural industries when trade partnering economies adopt similar policies. This is because the damage suffered by some agricultural industries, particularly livestock, will be offset by the global increase in prices or gains in other areas. Moreover, as claimed by Elliot et al. [10], a considerable portion of GHG reduced in developed countries (if under a CPJA Developed-like scenario) is expected to "leak" back into the environment when energy-intensive companies relocate to less-regulated areas. This also damages the company's domestic economy because it transfers precious jobs and production elsewhere.

Further, a study by the U.S. Economic Research Service reveals the long-term consequences of climate change-induced water scarcities on agricultural production shortages, indicating similar threats to productivity even without carbon regulations [50]. Thus, this study reveals that to reduce global GHG (a shared negative externality), the world must be willing to cooperate and to make short-term economic sacrifices.

A limitation of this study is that the model assumes there are no technological changes reducing the carbon intensity of agricultural production. With the appropriate data, however, this model could easily factor in potential scientific advances to produce updated results. Another limit of this study is that the accuracy of the results relies heavily upon the validity of the input data, which were obtained through estimation methods.

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The economic consequences of carbon taxes become less significant to national and global agricultural industries when trade partnering economies adopt similar policies.

Further work includes comparing different carbon policy proposals, since the model's flexibility enables the simulation of future policies proposed in this ongoing global dilemma.

A significant feature of this model is that different objectives can be set to achieve different goals, while the model's constraints or footprints can be customized and added upon; for example, one could add the data for the amount of water pollution caused by a single metric ton of commodity produced as another environmental footprint. The model's flexibility also allows for the addition of commodities, countries, modules (i.e. food processing), the number of years projected, and the customization of the policy itself. For example, the model could be expanded to different markets and could also project the impacts of other carbon or trade regulations (tariffs, quotas, etc.). Ultimately, the adaptability

of this model renders it a powerful tool for purposes ranging from policy and the environment to the economy and beyond.

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# MARY ZHU

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# Resolving Lacunae in the Reviews Market by Calculating the Reputation of a Reviewer

SURYA NARAYANAN, STANFORD UNIVERSITY

The advent and rapid spread of P2P technologies warrants a paradigm shift in the way we look at concepts of trust, reputation and reliability. Users wishing to maintain anonymity and privacy are finding it harder to transact online without ceding information to a third party. We find out what difficulties make reviewing products unappealing for users wishing to do so. To answer this, we analyze some of the metrics published by Amazon.com to see how people choose to trust reviews, if they do at all and what we can learn from the people that want to help others on the platform. This will help us assess the urgency to create value in a centralized, verified and accredited supply of honest information. Then, we can make a case for open, peer to peer, decentralized, anonymous marketplaces to capture underserved segments of the market using a higher bar for trustability.

## INTRODUCTION

Decentralized peer to peer (P2P) technologies, allow for unprecedented fluidity amongst users, allowing them to be producers and consumers of a service. P2P technologies' ability to function smoothly even if some nodes are not permanently connected to the network, and the distribution of ownership inherently diminishing the need for centralized authority to dictate allocation of responsibility, validate it as the easiest way for a multiparty marketplace to emerge and gain momentum. To be able to reach distributed ownership at scale effectively, however, is a herculean task. Companies like Amazon have succeeded in being able to reach that scale because of organizational tactics like investing most of their profits into R&D, giving very little to shareholders and diversifying extensively.

## AMAZON AND RATING SYSTEMS

Amazon's Vine program selects users to provide reviews for products that can be verifiably known as reputable and trustworthy. We dive into the helpfulness of the reviews provided by these users to see what kind of people Amazon Vine's program recruits and if they should be identified amongst review providers publicly.

## REPUTATION SYSTEMS

The central concept around trust and reputation systems is to develop a standardized way of scoring each and

every node in the network's faithfulness and truthfulness, borrowing from data from previous transactions and represent that scoring objectively to the network [1]. These scorings are then compared against each other to make a hierarchy ranging from highest scorers to lowest. This hierarchy is often mostly hidden from the rest of the network except for the top  $n$  most faithful reviewers.

Thus, to aid the establishment of a centralized reputation mechanism, our study is an analysis of what metrics we should look at to reliably construct a reputation score for Amazon buyers and sellers. So far, the applications of protocols that maintain orderly, functioning state in a network find their uses in file sharing, e-commerce and distributed computing for example.

## ROLE OF REPUTATION SYSTEMS

Existing reputation systems, ironically, aren't trusted enough to be universal. Existing decentralized approaches are vulnerable to deception by forged identities (Sybil attacks [2]) or sensitive information leakage. In this paper, we present some key features we'd like to see implemented into marketplaces to reduce their vulnerability, increase security and facilitate efficient, secure transactions.

Markets on the dark web were created to be able to detach user identity from their transactions and any digital footprint that they create. Users find it difficult to trust these services or even their surface web counterparts like

BitMarkets and OpenBazaar because they fear accountability lapses on part of both buyers and sellers. This is reminiscent of Akerlof's market for lemons [3], where the buyer is unaware of the quality of the product they are purchasing. Here, buyers on a marketplace like Amazon are unaware of the quality of sellers on the marketplace, and cannot verify the quality of goods prior to purchasing them, without being able to trust the reviews they might read. To help solve this, these services use escrow funds and third party arbiters to settle disputes respectively. Other services like Simility exist to protect people from fraudulent actors on marketplaces. However, users need to have the ability to ascertain the quality of the marketplace, as a whole - whether it be by governmental accreditation or by consensus of positive feedback.

## RELATED WORKS

### REPUTATION STRUCTURES

Milgrom et al. [4] provide a historical as well as theoretical account of the role of trade fairs in disseminating reputation information during the Middle Ages. Having a place, time and collective dedicated to trade helped set up a trusted quasi-marketplace environment that provided security to the traders involved to be able to share private information about reputation. To this end, game theoretic models to test whether people care about social and pecuniary payoffs can explain data

wide variety of experimental games, as observed by Fehr and Schmidt [5], Bolton and Ockenfels [6] and Güth and Ockenfels [7]. Thus, there exist precedents for players of the game valuing psychological payoffs as much as pecuniary ones. Huberman, Wu et al. [8] provide some bases of understanding the effects of pecuniary incentives on the honesty of reviews. Jurca and Faltings [9] provide some mechanisms to prevent fraud and deception detection and prevention.

### OBSERVATIONS ON THE USEFULNESS AND PREVALENCE OF FEEDBACK

The primary hurdle to get past is that once the transaction has concluded, buyers have no extrinsic incentives to provide others with feedback about their experience. Resnick and Zeckhauser [10] report that on online e-commerce platforms like eBay, post transaction feedback was provided in only about half the transactions that occurred on the platform. The information from the feedback is useful for all other future buyers on the market including the buyer that provides the feedback. Lin, Viswanathan and Prabahala [11] point out that the rightly incentivized seller is buyer agnostic i.e., has no preference over the quality of buyer. This observation proves useful to us when we discuss the alignment of incentives.

### DATA PROCESSING AND RESULTS

We have acquired a dataset comprising of ratings, select information about reviews and about reviewers on Amazon. The exercise thus comes down to examining what the distribution of quality amongst buyers and sellers is.

**Experience Scores:** We first attempt to find if there is a link between reviewers' experience and their helpfulness. While in real life, one would assume that drinking wine would contribute marginally positively towards becoming a better sommelier, we may have observed that writing an additional review may not always be marginally beneficial for the entire network. First, we inquire what the distribution of experience looks like when it comes to

writing Amazon reviews.

The mean number of reviews written is 8.278. We were rather surprised that the average number of reviews written by an average consumer was so low. Experience is positively skewed, most users on the platform will be lacking experience of having written reviews but they all might be more experienced or skilled review readers or quality verifiers. In this dataset of thousands of people, only a handful have written 30+ reviews and so we can safely say that a large proportion of the Amazon user base is relatively inexperienced.

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**Helpfulness Scores:** The metric we use to evaluate a reviewer's proficiency at reviewing is their average helpfulness score. We define the helpfulness score as the proportion of all reviews which users marked as helpful.

Reviews are written to help the buyers that follow and are ideally for both positive and negative comments about the product platform. The ideal user is one that will take the time to write

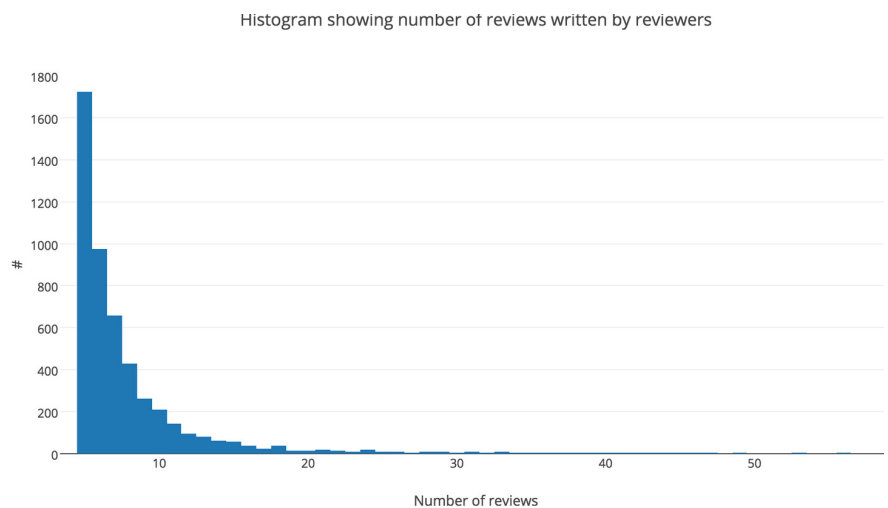


Figure 1. Histogram of Amazon reviews per reviewer

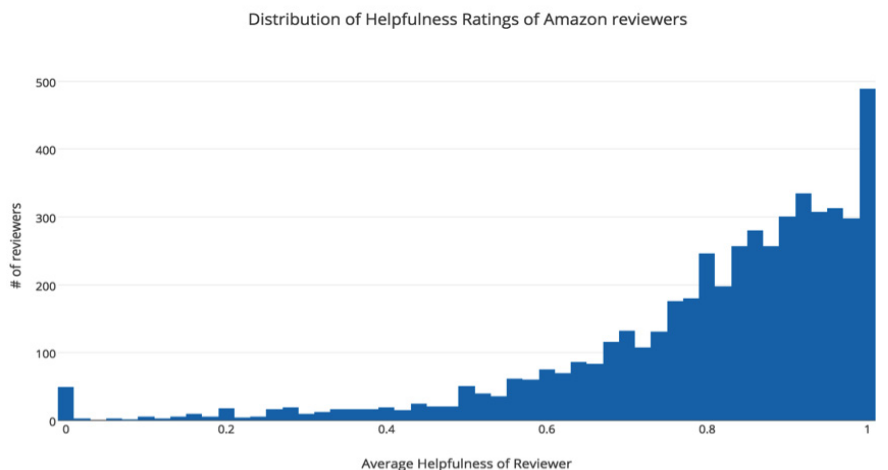


Figure 2. Histogram of helpfulness score per Amazon reviewer

quality assessments of their experiences, and we hypothesize that they are more likely to be experienced or at least involved buyers. They are more likely to rely on the collective experience of those on the platform to refine their own opinions.

It seems as if there is a mild positive bias where reviews might be marked to be more helpful than they actually are. This is beneficial for us because it shows us that there are gaps in the reviews market that can be fixed by democratization of authority. That is, if we had a democratic way of pointing out what aspect of reviews we find helpful and formed a consensus based categorization of helpfulness indicators, we could start a principle driven approach to cultivating positively helpful reviews.

**ARE USERS TRAPPED BY THE PLATFORM?**

Now, we answer the question of whether more helpful reviewers give more favorable, more positive ratings. This, if true, would imply that high quality users have an incentive to keep the marketplace running, and if this incentive was available to those who provided poor reviews to vendors on the marketplace.

Dividing the helpfulness data at the mean, we arrive at the following table.

Average Stars Given by Reviewer					
Helpfulness	1	1 - 2	2 - 3	3 - 4	4 - 5
0.8 or more	0.57%	0.90%	4.39%		
Less than 0.8	<u>1.09%</u>	<u>2.17%</u>	<u>5.97%</u>		

**Table 1.** Distribution of ratings and helpfulness

This representation shows us an interesting result. If a review were to be picked at random, the bucket it is more likely to be from is underlined in the table above.

In low scoring product reviews, unhelpful reviews outweigh helpful ones by a ratio of 2.5 to 1. In high scoring reviews, this ratio is reversed, with helpful reviews outnumbering unhelpful ones by 2.5 to 1. Essentially, reviews with a lower number of stars, are treated less favorably, on average.

To verify the hypothesis that

Amazon could use some more honesty amongst their reviewers, we examine what the behavior is amongst the most helpful reviewers who seem to have given high scores. Do they come from more experienced and trustworthy sources, enough to warrant their overrepresentation in the sample?

To think that over 53% of the transactions were rated at least 4 stars out of 5 implies that customers are rating the product more than the transaction. Of course, the products that remain on the platform are usually those that are rated higher, those that receive a significantly low rating, would have been taken down by the seller. Further, while assigning a rating, the influence of the product on the transaction and vice versa requires further analysis. Of all the 64.49% of users that received an average helpfulness rating of between 0.8 and 1, there is a 60% chance that the user has rated the product above a 4 on 5.

**THE RELATION OF REVIEWS TO OPINIONS - IMBALANCE BETWEEN EMOTIONS**

Our intrinsic valuation of opinions should ideally be higher than how much we value the objects that beget such opinions because opinions are spawned from deeper sentimentality and are more a part of the individual than the object.

That people, given the ability to monetize their opinion, will be willing to do so, is the macro-hypothesis we are studying. To that end, we now delve into the ecosystem of reviews and incentives to write them, to gauge whether it has all the moving pieces in place to support such payments and transactions. The first such moving piece, is the need to want to write good reviews.

We believe there exists an adverse selection problem in the reviews system. The motives of the firm optimized for economic production are that the best products stay on the market. This means that the products with the most positive reviews should be incentivized to stay. We believe that it is possible that people do not take the time to review the product because they aren't incentivized to help

their fellow shoppers and the merchant.

Further, we believe that users who have a negative experience with the product a while after they have purchased it, often don't write as strong a review, as users that have had a negative experience with the product just after purchasing it.

The demand side for reviews is that informative reviews irrespective of whether they're for or against the product, should be incentivized to stay. However, on the supply side, we believe there is an imbalance between the number of people that write reviews in support of the product and the number of people that write reviews condemning a product. Further, products that have more condemnatory reviews than supporting reviews, are removed from the marketplace, reinforcing the perception that the marketplace mostly contains positively reviewed products.

**INCENTIVES FOR WRITING REVIEWS**

Currently, consumers can't, won't and don't read the thousands of reviews for a particular product on an e-commerce site. Implementing a payoff mechanism via either determined pricing or auctions will induce people to a) write quality reviews and b) trust existing reputation structures in place more. This mechanism can be put in place by the providers of the service, or can be implemented in an innovative way where the service providers can gamify the process, awarding points to celebrate reviewers.

Amongst peers, people whose opinions we trust most are those who are both well liked by us and most like ourselves in preferences by taste. In a hierarchical reputation based system, these two qualities must be measured to optimize for symbioses.

As far as recommendations are concerned, we can infer that the large generality of the populous would accept the word of the few which is presented to be worth more or add more value than the opinions of the public. If a product has public approval ratings x on a public platform and a ratings y on a private platform, we hypothesize that the customer would be willing to pay to the tune of  $\text{Var}(x)/\text{Var}(y)$  for an exclusivity

group where  $p=y/x$ .  $p$  here is the average similarity or likeness of the trusted group members to the user who is seeking their reviews.

## FURTHER STUDY

### 1. EFFECT OF ANONYMITY ON LIKELIHOOD TO REVIEW

We further hypothesize that users are less likely to want to review goods on an anonymous platform than one where they are secure about identities and identity verification— this will lead to stronger polarization in reviews on anonymous platforms. If the platform is anonymous, users won't be able to trace back a review they wrote to the writer and hence credibility will have to be maintained by an arbiter. Reviewers here would review for the sole purpose of helping the rest of the community and not to want to boost their own reputation - the latter might happen as a byproduct of a good review - high polarization would also imply higher quality standards.

Further, we believe that the agreement amongst buyers must be measured too, answering the question 'do you agree with the opinions of this user' and the people that rate buyers should not be limited to those that have transacted with them before.

### 2. MEASURING REVIEW SELECTION BIAS

Users are sub-consciously looking for reviews that reinforce their opinion on the product so that they can validate their purchase to themselves. We believe that the first few reviews that a user will read, affect their opinion of the product heavily, and should be closely monitored to be ensured fair.

### 3. HOW EASY IS IT TO GAME THE SYSTEM?

Lastly, we want to find out how much having a bad rating or bad reviews affect sellers reputations and how much a hurt reputation hurts their revenues. This will tell us the efficacy of the platform to convey the emotions felt by non-trivial sub-proportions of the network populous. Suppose a malicious seller is hiring malicious reviewers to help boost their product. A thorough examination of the extent of the effects that these reviewers can have by slandering sellers and their

products, can be found in [12]. Is it more effective for the malicious reviewers to write inflated positive opinions about the product or to write inflated negative opinions about competitor products? Is it more effective to rate reviews that rate the product highly as helpful or reviews that rate a competitor product more highly as less helpful?

Reputation Networks: Reputation networks can be centralized or distributed.

1. In a centralized system, all the members of the network update a central register with their feedback from every transaction and a hierarchy of the best buyers and sellers can be calculated and maintained from this centralized register. Maintaining a centralized copy implies that it can be free from manipulation by any of the members.

2. In a distributed system, each node stores their history of previous interaction. If A is about to interact with B, A will query all the nodes B has interacted with. The advantage of this method of reputation capturing and categorization is that this allows A to query all those that interacted with B's reputations, the reputations of the nodes one more degree removed and so on and so forth. We can thus develop a contextual understanding of how good B is by weighing the rating of the buyers that they typically sell to or the average rating of the sellers they typically buy from.

## SUMMARIZED RESULTS

If Amazon could make the reputation of each user public and allow users to charge payments [13][14] for particularly detailed or helpful reviews about a buyer or seller, we believe there would be higher quality reviews displayed overall. We test out this hypothesis in the methodology, asking people how much they'd charge for writing reviews and how the monetization model would be.

1. More helpful reviews don't necessarily come from more experienced reviewers.

2. The opinions of those who have stellar transactions on the platform silence those that have everyday experiences.

## CONCLUSION

This study is rooted in a behavioral analysis of how people behave while transacting on the Internet—we dive deeper into the factors affecting their decision of which seller to choose and their opinion of the transaction overall. The end goal of this project is to aid and enable the easy and smooth transition to a world where the quality of content and commerce can be more easily verified. This means allowing different providers to meet the demand for each part of the production line, which allows for merchants to compete based on relative efficiency, ultimately leading to a more efficient market. Further, performing NLP analyses on the reviews themselves to eliminate all the spurious

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The opinions of those who have stellar transactions on the platform silence those that have everyday experiences

reviews or ones that aren't of a certain quality might be an effective next step. Precedents in this direction have been established by Whitby et al [15], Singh et al. [16] propose a schema by which we can bucket raters according to the ratings they give similar products and apply filters that communicate and collaborate across buckets to provide additional granularity and consistency to recommendations. ■

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# SURYA NARAYANAN

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# College Admissions in India: Mechanism Design Proposal

SONIA GUPTA, STANFORD UNIVERSITY

The Indian Institutes of Technology (IITs) are a set of prestigious, public engineering universities in India. Admissions are extremely competitive, with only 2% of the applicants (~10,000 students) being accepted as opposed to 5% at Stanford and 6% at Harvard. The IITs follow a common admission process for undergraduate admissions, using the Joint Entrance Examination – Advanced (JEE Advanced) to identify qualified students. IITs are spread across sixteen different locations in India. Students specify their location preference when applying. Each location then admits students to the university based on their ranks in the exam. Students with the highest ranks have the opportunity to choose their major first; remaining students subsequently choose their major in order of ranking, with the lowest ranking admits choosing their majors last. This paper analyzes the process by which students select their majors and school locations and explores three primary matching mechanisms: (1) Combined Student-Proposing DA, an offshoot of Shapley’s Deferred Acceptance Algorithm (DA), (2) Boston School-Choice Mechanism, and the (3) Shanghai mechanism, proposing policy changes that favor greater flexibility and efficiency as a remodeling of the current student-major-location assignment process.

## INTRODUCTION

The creation of the IIT system dates back to 1946, a period during which India vied for freedom from British rule. Sir Jogendra Singh of the Viceroy’s Executive Council appointed a committee that was responsible for the creation of Higher Technical Institutions, designed to attract talent and spur post-war industrial development. IIT developed as the brainchild of this committee, with the first institute being established in 1951. As of now, there exist sixteen IITs across India in various locations, all of which are highly competitive to gain admission to.

Currently, nearly 40% of undergraduates pursue a Bachelor of the Technology (BTech) degree, making it the most popular major. Other fields include Civil Engineering, Electrical Engineering, Mechanical Engineering, Chemistry, and Physics. Prior to attending university, students rank their preferred locations and majors. IIT’s matching algorithm then attempts to pair each student with their highest ranked location, letting students choose their major within each location in order of descending test scores. As a result, certain majors (i.e. Computer Science) reach

capacity early on in the process, thereby preventing multiple interested students from pursuing those fields. IIT also “locks in” major preferences, allowing only a small, select group of students to switch majors after their freshman year. At the end of freshman year, the school ranks freshmen’s academic performance and offers meritorious students the option to change their majors (similar to those who would receive the President’s Award for Academic Excellence at Stanford). Generally speaking, those who performed the best on the JEE Advanced perform the best at university. This correlation occurs due to various factors. According to India’s Ministry of Statistics and Program Implementation, students who score the highest on the JEE advanced report being more diligent in their studies. This work ethic could translate to university, with high performers working harder and scoring better than their less conscientious peers. With that said, the majority of students given the option to change majors have already selected their most preferred major prior to freshman year. Consequently, few changes take place with 99% of students remaining fixed in their program for all four years.

Furthermore, in order to maximize

their chances of gaining admission to IIT, several students receive tutoring for the JEE Advanced. Tutoring services are highly priced though, thereby limiting access to lower-income students and those from less-equipped regions. As a result, those from lower-income families typically end up performing worse on the exam. Indeed, according to the Indian Statistical Institute, students whose parents earn more than 4.5 lacs (~\$6921) annually are four times more likely to outperform students whose parent earns less than 1 lac (~\$1538). Those who gain admission usually rank on the lower end of the spectrum, thus inhibiting them from pursuing their major of choice at their preferred location or incentivizing them to manipulate their preferences in order to study their preferred major at a less popular location. Consequently then, the current matching mechanism results in unstable, inefficient matches that are not always strategy-proof.

As it stands, IIT uses a centralized clearinghouse to match students with their locations and majors based on the student-proposing DA algorithm. As

stated in the paper, Dynamic Reserves in Matching Markets, while the student-optimal mechanism is ordinarily stable and the dominant strategy is ordinarily strategy-proof, IIT relies on two iterations of the mechanism. In this situation then, the outcomes are not always stable and strategy-proof. Additionally, the traditional DA algorithm lacks Pareto efficiency, an economic state obtained when one party's situation cannot be improved without making another party's situation worse. However, according to economist Al Roth, it is still the most efficient of all existing stable school choice mechanisms. Now let's examine how IIT admits its students to various locations and majors.

**Step 1:** Each qualified student ranks their preferences for school location. For each school  $s$ , up to  $q_s$  applicants who have ranked the school as their most preferred choice are tentatively admitted to a certain location. **Step 2:** School  $s$  ranks the  $q_s$  applicants admitted in Step 1 by their test scores. It then prioritizes those with the highest test scores, allowing student  $q_1$  to choose his major first,  $q_2$  to choose his major second, and so on. If a certain major reaches capacity, student  $q$  is then forced to apply for his second-choice major. If, at the end of the process, there are spots remaining, school  $s$  repeats the process, now admitting students who have ranked it as their second-choice location. If, however, there are no spots remaining in the IIT location, then the location terminates the process. Any students who have failed to be admitted will go

through additional recruitment. Step  $k$ ,  $k \geq 2$ : Each student rejected from his preferred IIT location at step  $k-1$  applies to his next most preferred location. He then repeats the process at locations that have not reached capacity. Final: The algorithm terminates when all admits have been assigned to a certain location and a specific major within that location. IIT only accepts as many people as they have room for; as a result, no student will be left behind or unmatched at the conclusion of this process. Students may, however, be assigned to a less than optimal location or major.

For now, let's assume that schools have strict as well as responsive preferences over students based on their test scores. Generally, while students may not agree on the most preferred set of stable outcomes, they are in consensus that there exists a third stable outcome  $z$  that is in their common interest to pursue (Sonmez 201). This occurs for a couple different reasons. First, most students are attracted to the most well equipped locations. Thus, most students' true rankings of their preferred locations are the same. In addition, there exists a general consensus among students about which majors are the "best", with Computer Science being most sought after, Electrical Engineering being the second most preferred, and so on. This pattern of common interests creates a lattice containing the set of outcomes (as shown below) giving the partial order of the students' common interests. The optimal outcome for students is the highest element of this lattice (Computer Science degree, Delhi location). This

lattice does not represent all students though, as there are some students who will prioritize locations and majors differently.

All together, the current matching system causes students to manipulate their true preferences in order to have a higher chance of being placed within a favorable department or location. As we will soon see, this process can trigger justified envy as well, a phenomenon where more qualified students end up in less desired majors than their less qualified counterparts.

## OBSERVATIONS AND ISSUES

While the current process of allocating majors and locations to students might take into account their preferences, it also causes students to manipulate their preferences in order to increase their chances of getting placed in a certain major or location. For instance, say student A wishes to study Computer Science and attend IIT-Delhi. However, he knows that the Delhi location is more competitive than the Manipur location; correspondingly, his chances of studying CS at Delhi are lower than at Manipur. He then has to choose – if he values studying CS more than he does studying in Delhi, it is in his best interest to misrepresent his preferences, ranking the Manipur location above Delhi. Note that this situation occurs only when students value majors over locations. If student A were to prioritize staying in Delhi over studying Computer Science, it would be in his best interest to report his preferences for majors truthfully. Manipulating his major preferences would be counterintuitive since they have no bearing on location.

Additionally, student A would take a significant risk in listing the Delhi location if the number of students ranking Delhi highly is said to exceed the capacity there. While the Indian system would not preclude student A from attending IIT should he fail to secure a spot in Delhi, it could cause him to study a less preferred major at, say Manipur, than he would have had he ranked Manipur above Delhi. For example, assume student A can study Computer Science at Manipur should he rank it first. However, because he ranks Delhi first and because it takes time for each

	Delhi	Mumbai	Manipur	Chennai	Kharagpur
Computer Science	50	50	50	50	50
Electrical Engineering	50	50	50	50	50
Mechanical Engineering	50	50	50	50	50
Civil Engineering	50	50	50	50	50

**Table 3.** Model validation with Average Absolute Relative Error (AARE) between historical and projected data of countries/regions and the world. 50 students are ultimately assigned to each matching. The model assumes 1000 students total, with 5 locations and 4 majors for this example. In reality, there are many more options and students. Locations are ordered by student preference from left to right, with Delhi being the most preferred. Majors are ordered by student preference from top to bottom, with Computer Science being the most preferred.

location to admit students, the Manipur location first admits students who have prioritized it in the rankings. Thus, by the time student A is denied entrance to IIT-Delhi, the Computer Science spots at IIT-Manipur may be filled up. As a result, A would then have to settle for studying say, Electrical Engineering. In this case again then, it is in student A's best interest to rank IIT-Manipur above IIT-Delhi though he prefers the latter.

Furthermore, the current system breeds ground for justified envy. An allocation eliminates justified envy when there are no blocking pairs. In other words, there are no two participants  $x$  and  $y$ , each of whom prefers the other to their partner in a matching. Let's look again at the case where student A is denied entrance to IIT-Delhi and ends up studying Electrical Engineering at IIT-Manipur. Now let's say there exists some student B whose scores are lower than A's. However, because he ranked Manipur higher than A did, he had the opportunity to choose his major first. Thus, even though A is more qualified than B to study CS at Manipur, he is relegated to studying EE, thereby giving strict priority to students who rank a given location highly despite having lower test scores.

Lastly, as written in the paper, College Admissions with Entrance Exams: Centralized versus Decentralized, it is important to note that no mechanism exists such that it is Pareto efficient and eliminates justified envy. Thus, any proposed improvements to the current system would either increase efficiency or mitigate justified envy, but not both.

## PROPOSED ALTERNATIVES TO CURRENT PROCESS

This section proposes a couple alternatives to the current market design, comparing each one to the current matching mechanism. It then discusses the advantages and disadvantages of each proposed alternative and how we should weigh different factors when employing different algorithms. The alternatives seek to promote stable matches with Pareto-efficient,

strategy-proof outcomes. Currently, the central clearinghouse in IIT college assignments draws on two rounds of the Student-Proposing Deferred Acceptance Algorithm (DA). One round deals with students' preference for location; the second constitutes students' major preferences and assigns them accordingly in order of ranking.

While this mechanism is not strategy-proof, a combined DA would be both strategy-proof and Pareto-efficient (Min 12). Furthermore, it would produce stable matches as well. Whenever college choice rules expand to allow more students, the outcome of the combined student-proposing DA would improve for all students (Min 13). In this case, the result would be the same if we employed the Serial Dictatorship (SD) mechanism, since all colleges express the same preferences

“All together, the current matching system causes students to manipulate their true preferences in order to have a higher chance of being placed within a favorable department or location.

for students (solely based on test scores). The SD mechanism specifies an order over agents, letting the first agent attain his highest-ranked preference, the next agent attain his highest-ranked preference from the remaining options, and so on. Here, the colleges act as agents with the students as their preferences. According to Theorem (Svensson 1998), “A mechanism is group strategy-proof and neutral if and only if it is a serial dictatorship.” While there are many benefits to this solution, there are also glaring drawbacks. Most notably, there exist sixteen IITs across India, each with multiple major offerings. It is nearly impossible, then, for students to rank all their preferences for location and major simultaneously, and for schools to look at hundreds of thousands of priority orders. Thus, while the combined student-proposing DA is a practical solution in theory, it is harder to implement in practice.

Another potential algorithm would rely on the Boston mechanism to match students with majors and IIT locations. On one hand, the general Boston mechanism neither eliminates justified envy nor incentivizes truthful reporting (Hafalir 5). It is, however, Pareto efficient. As described in the paper, From Boston to Shanghai to Deferred Acceptance, the Boston mechanism constitutes a two-step process. First, each school considers students who have listed it as their first choice and assigns seats to those students in priority order. Similarly, schools would consider students who had listed them as their first choice and assign them to their preferred major in order of test scores until either no spots remains or no student remains who had listed the school as his first choice. If the number of students requesting a certain school exceeded that school's capacity, the school could then choose students with the highest test scores and assign remaining students to their subsequent preferences. In the next step ( $k$ th step) of the Boston mechanism, each school with available seats would consider students who had listed it as their  $k$ th choice and assign seats accordingly with regards to priority order. Likewise, any college with space left in its departments would assign students in priority order until no space or students remained, eventually terminating the process when each is not necessarily more student-optimal. Overall then, though not the optimum solution in theory, the iterative Boston mechanism seems here to be the most practical while still mitigating some of the shortcoming of the current matching process.

## CONCLUSION

The current student-location-major assignment process as conducted by the Indian Institutes of Technology has its benefits and drawbacks. While it attempts to take into account student preferences, the resulting outcome can be unstable and can incentivize students to deliberately manipulate their rankings in order to study a more preferred major

at a lower-ranked location. This paper suggests several alternatives to the current algorithm, weighing the pros and cons of each. While I discovered the combined student-proposing DA to be the optimal mechanism in theory, I hypothesized a modified version of the Boston mechanism to be more optimal in practice. Ultimately, IIT must explore different matching strategies to definitively evaluate the most favorable algorithm; nonetheless, the policy changes proposed here should all enhance the current matching process in different ways, if implemented correctly. ■

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## SONIA GUPTA

Sonia is a junior at Stanford University majoring in Economics. Her dad - Mukesh Gupta - grew up in India and attended the esteemed Indian Institute of Technology (IIT) Delhi, where he majored in Civil Engineering. While he thoroughly enjoyed his college years, he also criticized the application process, especially with regard to major selection. As a result, Sonia decided to look into the process and use her knowledge of economics to determine ways to refine it in ways that would enhance both efficiency and justice.

# Predictive Model For FAA Phase III Wake Turbulence Recategorization

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This paper proposes a method for calculating hourly density and wind-based dynamic wake turbulence separation distances at airports to predict mixed operations throughput and revenue changes. Newark Liberty International Airport (EWR) anticipates Phase III dynamic wake measurement devices by 2020. EWR airport data is used to develop a predictive model to current throughput comparison. First, the effect of wake vortex decay on aircraft control and surrounding airflow is introduced. Then, a control table for the sample fleet mix is created using present (Phase I) recategorization requirements and average atmospheric data at EWR. Dynamic separation distances are predicted using two atmospheric variables - air density and surface wind directions - and compared to current throughput. An experimentally derived equation for required decay distance (RDD) is used to determine dynamic wake separation distances. Dynamic capacity impacts on airport revenue are then rivaled with current revenue data and model limitations are acknowledged. A cost-benefit analysis determines the convenience of implementing Phase III equipment relative to the change in throughput reflected by the prediction model. Areas of potential air traffic conflicts posed by the diversification of approach paths due to ground-based augmentation systems (GBAS) are highlighted. The presence of wake turbulence in areas other than the runway used for approach or departure necessitates a larger spread of wake detection systems. The following predictive model for RECAT Phase III implementation at US airports provides a convenient means for determining capacity changes in airport operations in addition to the burden of investment in Phase III infrastructure and maintenance. In this case study on Newark Liberty Airport, we concluded that dynamic turbulence spacing derived from wind and air density data increased mixed capacity throughput at EWR by 29.4%.

## INTRODUCTION

### WTMD/A ANTICIPATION AT EWR

Wake Turbulence Mitigation for Departures and Arrivals (WTMD/A) is anticipated to be available at EWR by 2020 for Runways 4L and 4R [1]. WTMD will eliminate the need for wake vortex separation behind a Boeing 757 or Heavy aircraft departing on the adjacent runway when specific wind conditions exist that reduce the vortex hazard. Wake Turbulence Mitigation for Arrivals (WTMA) is also anticipated at EWR by 2020. WTMA features a wind detection algorithm to permit reduced separation between closely-spaced parallel arrivals to Runways 4L and 4R under specific wind conditions. This paper uses EWR as an example case for dynamic separations expected from programs like WTMD/A and FAA RECAT.

### CHARACTERISTICS OF WAKE VORTEX FLOW

Before introducing calculations used in the dynamic model, it is important to describe the movement of wake vortices behind an aircraft in order to isolate surface wind conditions that minimize required spacing between the leading

and trailing aircraft. Wake turbulence separation standards between aircraft on approach are determined by the initial circulation of the leading aircraft's wake vortices, atmospheric characteristics, and the stability of the trailing aircraft. This is the primary reason why the classifications for aircraft has been divided by weight, as larger aircraft are more capable of counteracting induced roll caused by wake turbulence and produce larger wake vortices due to their larger lift creation. It was not until the collection of larger aircraft data sources that this equation could be expanded

to consider dynamic qualities like air density, wind speed and direction in order to create real-time headway separations which optimize the capacity of the existing runways at an airport.

Wake vortices are created by the gradated air pressure differential along an aircraft's wing. These vortices are centered at the tips of the wings and expand in radius as they develop behind the aircraft. The air flow profile within these vortices is strongest at the edge of the vortex core, which may exceed 300 ft/s [2]. For the purposes relevant to this report, all wake vortices considered

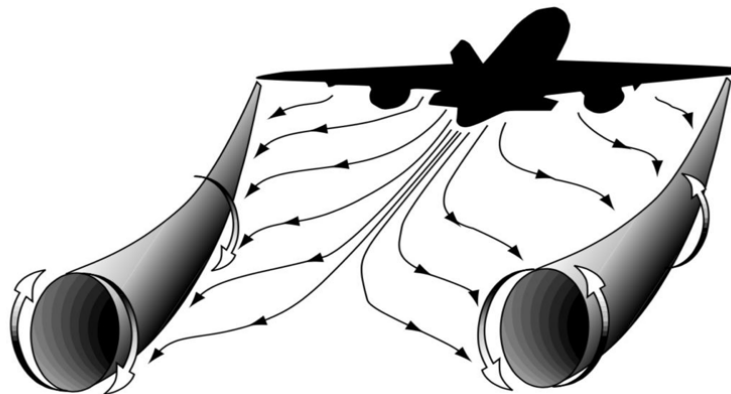
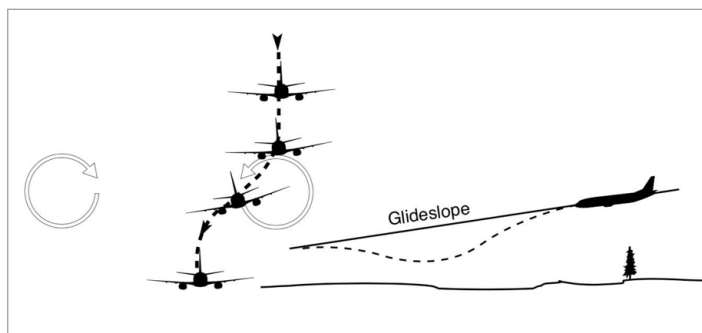
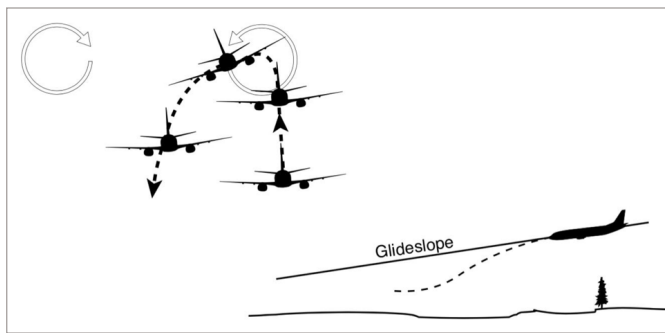


Figure 1. Wake vortices trail behind and below an aircraft. Required decay distance is affected by atmospheric factors such as air density and wind velocity [4].



**Figure 2.** Rear and side views (from left to right) of an aircraft laterally entering a wake vortex. The aircraft can stall and lose significant altitude even when partially intersecting a vortex [4].



**Figure 3.** Rear and side views of an aircraft vertically entering a wake vortex. The climbing aircraft rotates in the direction of the interfering vortex and stalls until it regains smooth airflow [4].

are during the approach and departure paths. Airflow disruptions created by ground obstacles are not included in the calculations. Wake vortices develop as the wings of the aircraft create lift and flow both clockwise and counterclockwise in the opposite direction of the aircraft as two cylindrical vortices. Undisturbed, a set of wake vortices expand to an area of roughly two wing spans in combined width and one wing span in height of the aircraft which created the vortices. These vortices will begin to drop in altitude at a rate of 2-2.5 m/s [3] until their rate of descent levels off at roughly 150-275 m below the flightpath [4].

The flow of air behind an aircraft that results in vortices and the respective rotational directions of these vortices is illustrated in Figure 1. The vortex exerted by aerodynamic forces along the left wing rotates clockwise and the vortex exerted by forces along the right wing counterclockwise.

The primary danger introduced by wake vortices is their production of induced roll in the trailing aircraft's flight path, resulting in uncontrollable rotation of the trailing aircraft. Trailing aircraft encounter induced roll - potentially uncontrollable rolling moment caused by airflow separation - when the rotational force of the vortex stalls the wing. This is often the case when the trailing aircraft has a smaller wingspan than the aircraft that creates the vortex. Additionally, rapid aircraft displacement can occur when a trailing aircraft does not fly directly into the center of a wake vortex, but instead crosses into it laterally. Encounters of this type can

result in the aircraft deviating from the flightpath both horizontally and vertically. Figure 2 shows aircraft spatial displacement due to wake vortex influences as the aircraft enters the vortices laterally. Figure 3 shows aircraft spatial displacement due to wake vortex flow fields as the aircraft enters the vortices vertically.

## PRESENT RECATEGORIZATION MODELS

The FAA wake turbulence recategorization (RECAT) phases were established as part of FAA's NextGen initiative to increase wake turbulence safety while maximizing airport throughput. RECAT Phase I, established in 2012, replaces the preceding tri-weight category separation requirements (light, medium, and heavy) with an extended six-category matrix. Most airports are only beginning to transition to Phase I recategorization rules. RECAT Phase II expands on the Phase I matrix with 10,000 aircraft model-defined pairs. Phase III implementation provides dynamic, weather-dependent wake turbulence separation distances based on real-time analysis of leading aircraft vortices.

### RECAT PHASE I

The Phase I model for spacing was developed using LiDAR (Light Detection and Ranging), Pulse Doppler, and radar at the San Francisco (SFO), Memphis (MEM), John F. Kennedy (JFK), and London Heathrow (LHR)

airports over a period of three years to derive the following conservative linear model for wake turbulence separations using a 95% confidence interval. The spacing is determined by the dissipation period of the initial vortex circulation loop (a measurement of vortex intensity), calculated using the following equation [5]:

$$\Gamma_0 = \frac{m g}{\rho v s B} \quad [1]$$

where  $m$  is aircraft mass in kg,  $v$  is airspeed in m/s,  $\rho$  is air density in kg/m<sup>3</sup>,  $s$  is the wing load distribution coefficient ( $\pi/4$ ), and  $B$  is wingspan in  $m$ . The equation can be modified to include the trailing aircraft's roll moment coefficient, useful only for larger planes with greater roll resistance:

$$\Gamma(d) = \frac{mg}{\rho v s B} \left( 1 - \frac{mg}{12 \rho \pi v^2 s^3 B^3} d \right) \quad [2]$$

where  $\Gamma(d)$  is the vortex circulation dissipation period and  $d$  is the distance of the trailing aircraft from the vortex. This model for vortex dissipation (in m<sup>2</sup>/s) is used in the following graph to demonstrate the decay time for larger aircraft.  $T(d)$  can be rearranged to reflect the required decay distance (RDD) based on FAA minimum acceptable wake vortex circulation values ( $T_{\min}$ ):

$$d_r = \frac{12 \rho \pi v^2 s^3 B^3}{mg} \left( \frac{mg}{\rho v s B} - \Gamma_{\min} \right) \quad [3]$$

The required decay distance can be quadratically correlated with aircraft weight as shown in Figure 4. This trend shows that a minor change in aircraft weight corresponds to a minor change in RDD, accommodating the wide RDD ranges used for each aircraft wake category A-D.

Table 1 divides wake separation minima for the following aircraft categories A for Super Heavy, B for Upper Heavy, C for Lower Heavy, D for Upper Large, E for Lower Large, and F for Small category aircraft. [6].

**RECAT PHASE II**

The Phase II recategorization model expands on the static RDD equation used in Phase I with additional aircraft categories. Phase II follows the path of current European recategorization programs in scaling the wake turbulence separation matrix by aircraft model rather than weight. It uses a larger dataset from 230,000 pulsed LiDAR departure and approach measurements at 32 US airports to categorize 123 aircraft models between categories A-G, comprising 99% of fleet mix at US

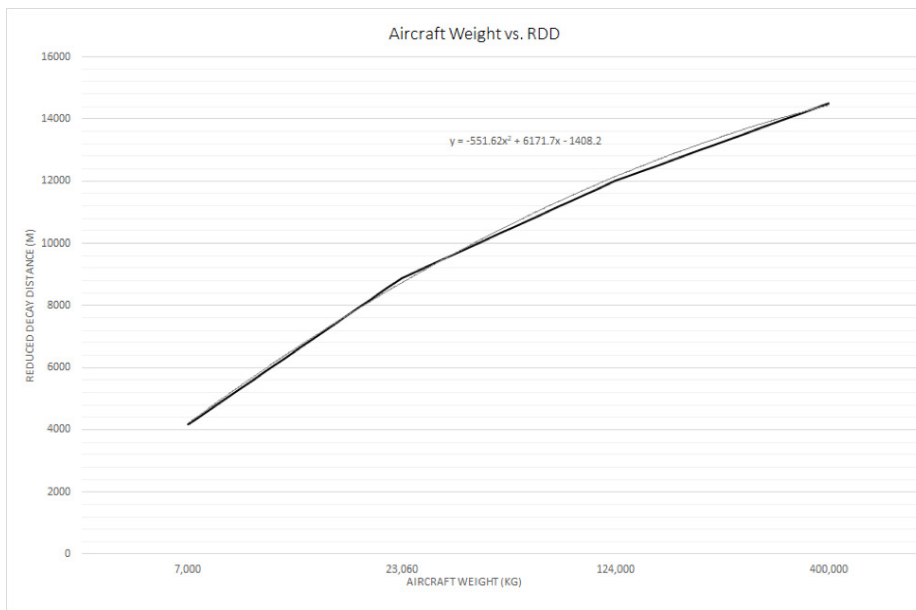
airports [7]. Like Phase I, RECAT Phase II uses wake vortex circulation and roll moment to determine aircraft separation. The roll moment coefficient can be calculated using the following equation:

$$RMC = \frac{\Gamma}{v\beta} \tag{4}$$

where  $T$  is the vortex circulation dissipation period of the leading aircraft calculated using Eq. 2,  $v$  is the trailing aircraft speed, and  $\beta$  is the trailing aircraft wingspan. Roll moment coefficient is used for larger aircraft which roll more slowly, while vortex circulation dissipation period is used for smaller aircraft which have a low roll resistance.

**RECAT PHASE III**

The Phase III recategorization model envisions dynamic separation distances based on each aircraft’s unique characteristics combined with environmental conditions using Doppler, LiDAR, and other systems. Dynamic measurements account for the effect of atmospheric conditions on vortex decay including: atmospheric turbulence, viscous interactions, surface winds, buoyancy, atmospheric instability due to non-standard pressure or temperature lapse rates, ground obstacles, and terrain geometry. Our prediction model uses hourly air density and surface wind information to measure a theoretical RECAT Phase III capacity at Newark Liberty International Airport (EWR).



**Figure 4.** Graph plotting Aircraft Weight in kilograms vs. Required Decay Distance in meters. The quadratic trendline is used to determine RDD ranges for each category of aircraft A-D listed in Table 1.

RECAT Phase I Aircraft Wake Separation (nm)							
		Trailing					
Leading	RDD (m)	A	B	C	D	E	F
A	$d_r \geq 12000$	-	5	6	7	7	8
B	$12000 > d_r \geq 10000$	-	3	4	5	5	5
C	$10000 > d_r \geq 5000$	-	-	-	3.5	3.5	5
D	$d_r < 5000$	-	-	-	-	-	5

**Table 1.** RECAT Phase I aircraft wake separation distances in nautical miles. The Phase I standard is used to develop the control table (Table 3) for the calculations performed in the dynamic model.

**PREDICTIVE MODEL CALCULATIONS**

**PROCEDURE**

Developing a predictive model begins with the control case table for Phase I RECAT mixed capacity. The table uses existing FAA separation ratios to define separations for each combination of aircraft in the sample mix. Then, hourly wind and density data from 2015 New Jersey ASOS measurements [11] are incorporated into separation calculations using capacity formulas based on wind velocity components and Phase I experimentation. Finally, an estimate of revenue impact generated by predicted Phase III capacity changes in



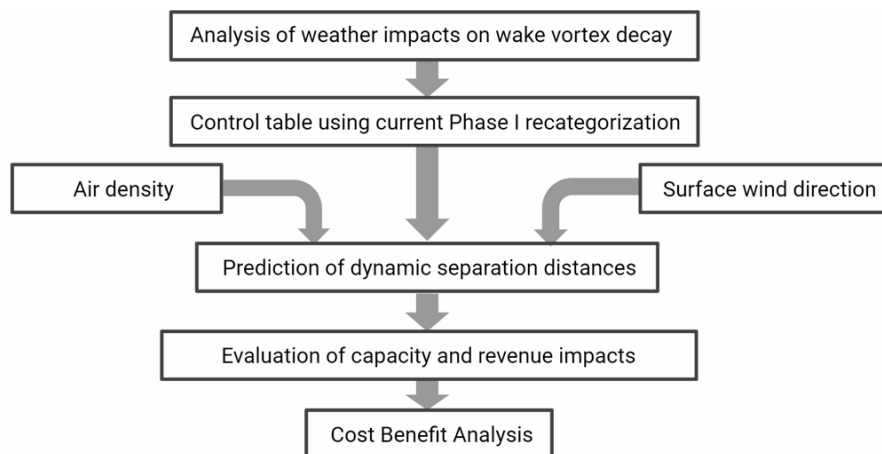


Figure 5. A flowchart summarizing the calculation steps in this paper to guide a candidate airport in determining the practicality of dynamic wake turbulence equipment.

Control Aircraft Characteristics							
Category	Weight (kg)	Wingspan (m)	Avg. Density (kg/m <sup>3</sup> )	RDD (m)	Velocity (m/s)	T(d) m <sup>2</sup> /s	T <sub>min</sub> (m <sup>2</sup> /s)
A	400,000	80	1.24	14,500	160	315	100
B	124,000	48	1.24	12,000	150	290	100
C	23,060	33	1.24	8870	70	227	100
D	7,000	11	1.24	4164	62	100	100

Table 2. Control aircraft characteristics arranged by weight category. The air density value remains constant to simulate static spacing.

Leading	Type	Trailing (Aircraft)						
		RDD (m)	RDD (nm)	Velocity (nm/s)	A	B	C	D
A	Super	1450	7.8	0.0431965	2.3	5.9	6.8	6.8
B	Heavy	1200	6.48	0.0404968	2.7	4.3	5.4	5.4
C	Large	8871	4.79	0.037797	2.4	3.8	3.8	3.8
D	Medium/Small	4164	2.2	0.0334773	2.2	2.2	2.2	2.2

Table 2. Control separations table for capacity and revenue comparison with dynamic model results.

2015 is performed.

**MODEL CONTROL SEPARATIONS FOR SAMPLE FLEET MIX**

The dynamic model uses a fleet mix of four aircraft for categories A-D. Total circulation (m<sup>2</sup>/s) is calculated using the Hallock-Burnham wake vortex model [8] for each aircraft and substituted into Eq. (2) along with the average air density at EWR in 2015 to derive control case RDD values for each aircraft (Table 2).

The full RDD value of the leading aircraft is used for the maximum separation scenario, which occurs when the lowest-weight aircraft (aircraft D) trails the leading aircraft. For all other scenarios (leading-A/B/C/D and trailing-A/B/C), each RDD value is scaled using RECAT Phase I wake separation allowances for the following control case separations (Table 3).

With the same category fleet mix used as the dynamic model, the control case yields a mixed capacity of 63 aircraft per hour and average arrival separation 112 seconds. This throughput represents a minor increase from 2015 average hourly capacities at EWR (47 aircraft per hour). The control capacities will be used to determine the change in throughput and airport revenue brought about by dynamic model capacities.

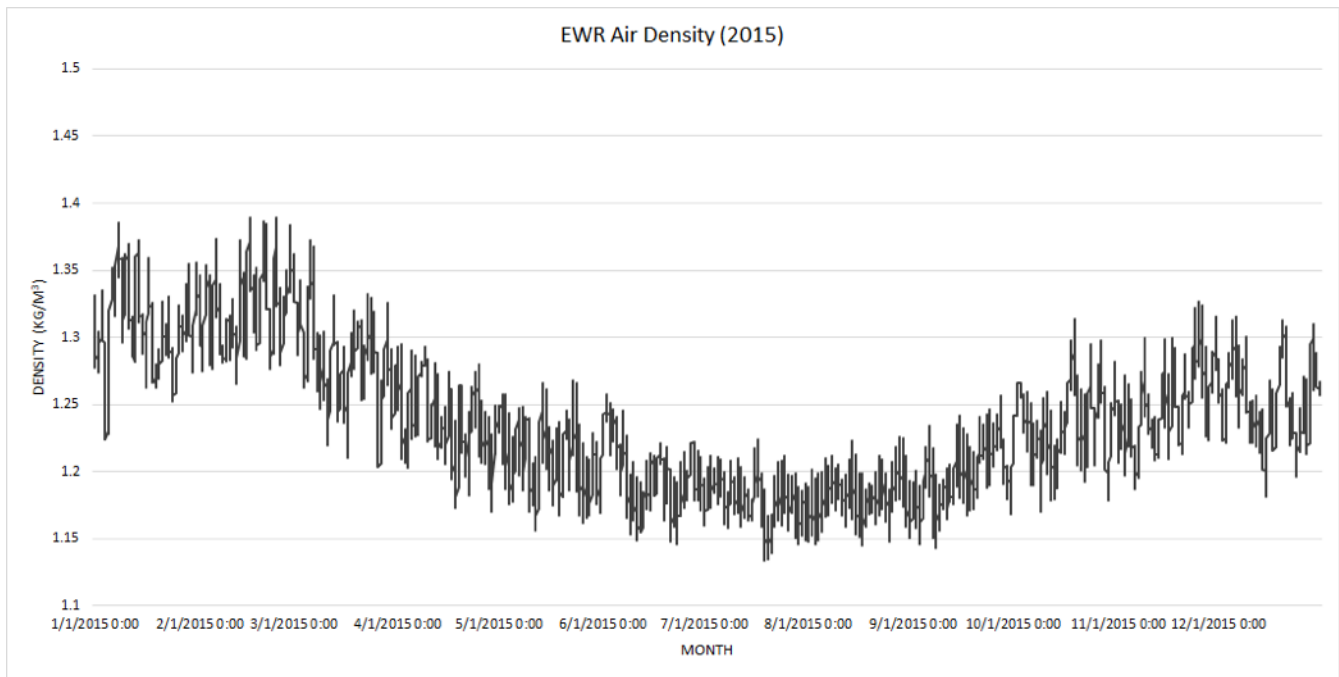
**DYNAMIC WAKE VORTEX RDD VARIABLES**

*Air Density*

The following equation is used to obtain hourly air density levels at EWR in 2015 [9]:

$$\rho = 1.2929 \times \frac{273.15}{T} \times \frac{B-0.3783 p_v}{1.013 \times 10^5} \quad [5]$$

where *T* is temperature in Kelvin, *B* is barometric pressure in Pa, *p* is partial vapor pressure in Pa, and *p<sub>a</sub>* is density in kg/m<sup>3</sup>. Phase I and Phase II recategorization use a density-dependent equation for RDD, but separation is determined using an aggregate measurement over several years as opposed to a Phase III dynamic model which calculates RDD based on real-time air density values. The predictive model at EWR uses hourly New Jersey ASOS data to simulate near-



**Figure 6.** Air density changes during the year 2015 at Newark Liberty International Airport based on New Jersey hourly ASOS data. Wake turbulence spacing increases with air density.

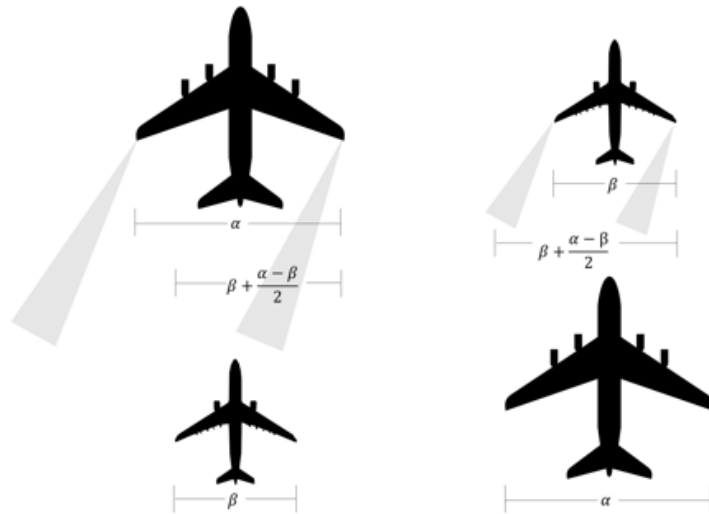
real-time density changes encountered by wake turbulence sensors. The RDD equation (Eq. 3) makes evident that the largest dynamic spacing distances will be employed between March and November when air density is lowest (Figure 6).

#### Surface Winds

Surface crosswinds with reference to runway orientation  $040^\circ$  are used to measure parallel mixed operations capacities for runways 04L and 04R at EWR. The length of time ( $\tau_{\text{clear}}$ ) before the crosswind displaces the leading aircraft's vortices clear of the trailing aircraft's wingspan can be calculated using Eq. (6):

$$\tau_{\text{clear}} = (\alpha - \beta) \frac{1}{v_x} + \beta \quad [5]$$

where  $\alpha$  is the wingspan of the larger category aircraft in m,  $\beta$  the wingspan of the smaller category aircraft in m, and  $V_x$  the crosswind component in m/s perpendicular to a  $040^\circ$  approach path.  $V_x$  can be calculated by taking the absolute value of wind direction subtracted from  $040^\circ$  and multiplying the velocity by  $\sin(\phi)$ .  $\tau_{\text{clear}}$  assumes that leading aircraft wake vortices must be completely clear of the trailing aircraft and that the vertical component



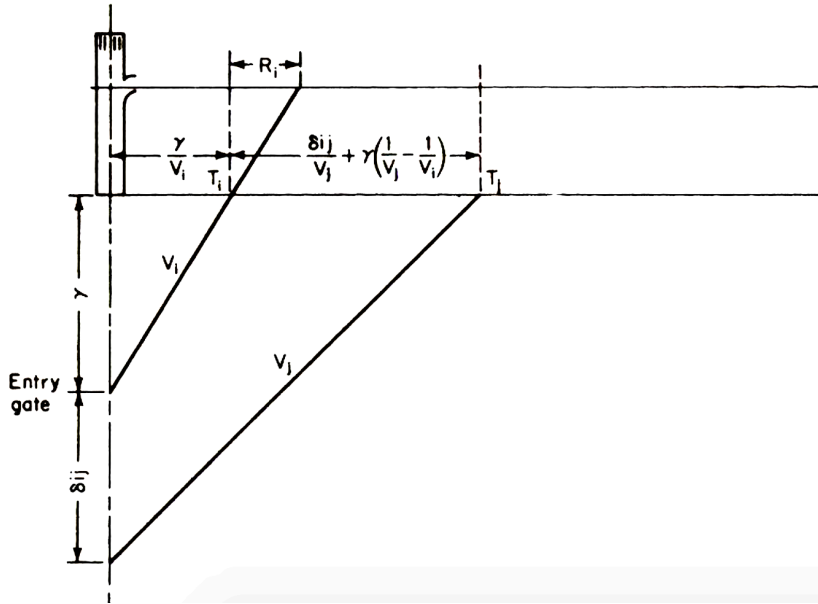
**Figure 7.** The set of equations used to determine the length of time before a wake vortex clears the wingspan of the trailing aircraft. On the left, a small trailing aircraft follows a heavy leading aircraft. On the right, a heavy trailing aircraft follows a small trailing aircraft. The equation for  $\tau_{\text{clear}}$  remains the same for both cases.

of the surface wind does not extend or diminish intensity of the vortices. If  $\tau_{\text{clear}}$  is greater than separation time using density-based dynamic RDD Eq. (3), then RDD is used for minimum separation distances. The equations are illustrated using trailing and leading aircraft and a sample left-bound crosswind (Figure 7).

#### DYNAMIC SEPARATION MODEL

Dynamic separation distances for different A-D leading and trailing combinations are calculated using data from each hourly EWR ASOS recording. Eq. (3) is used to calculate distance separation with hourly density as input, and Eq. (6) to calculate time separation using hourly wind velocities. A landing roll buffer of 60 seconds is added to each separation distance. Density-based

dynamic separation distances are then converted to time-based separations using the following conservative headway formulas and corresponding interarrival diagram [10]:



Opening Case ( $V_j < V_i$ )	Closing Case ( $V_j > V_i$ )
$C_m = \frac{1}{E(\Delta T_{ij})} (1 + \sum_n n_d p_{nd})$ <p style="text-align: right;">[7]</p>	$\Gamma_{ij} = \frac{\delta_{ij}}{V_j} + \kappa$ <p style="text-align: right;">[8]</p>

where  $V_j$  is the speed of the trailing aircraft,  $V_i$  is the speed of the leading aircraft,  $\gamma$  is the length of the approach path for 04L/04R (5 nm used for model),  $\delta_{ij}$  is the 60-second landing roll buffer, and  $T_{ij}$  is the separation time for each aircraft. In the opening case, the velocity of the trailing aircraft is lower than that of the leading aircraft. In the closing case, the opposite is true; thus, the time interval between the two aircraft is only affected by wake turbulence separation and does not include approach path distance. The lower minimum separation time for each ASOS recording is then multiplied by a probability matrix for the 16 A-D combinations using 2014 fleet mix data:

$$C_m = \frac{1}{E(\Delta T_{ij})} (1 + \sum_n n_d p_{nd}) \tag{9}$$

where  $E(\Delta T_{ij})$  represents the expected value of interarrival times,  $\eta_d$  the number of departures released between arrivals, and  $p_{nd}$  the probability of releasing  $\eta_d$  departures in each gap. This model uses

$\eta_d = 1$  and  $p_{\eta_d} = 1$  (100% probability that the number of departures  $\eta_d$  will be released between each arrival) to obtain the mixed capacity for runways 04 Left and 04 Right at Newark Liberty International Airport.

**RESULTS**

The dynamic density and wind-based model yields an arrival capacity of 45 aircraft per hour and a mixed capacity of 90 aircraft per hour. Compared to control separations without hourly density or wind-based adjustments at EWR, model mixed capacity projections represent a 29.4% increase in average mixed operations on runways 4L and 4R. The 120 operations/hr maximum cap occurs when a high crosswind velocity shifts leading aircraft wake vortices clear of the trailing aircraft's path within a few seconds, leaving only the 60 second buffer for spacing. A 50 operations/hr minimum cap occurs when light wind conditions prevail, prioritizing density-based spacing. Instances where

spacing reaches the maximum cap of 120 or minimum cap of 50 are identified as outliers and eliminated in the final operations/hr graph (Figure 8).

Using FAAASPM data [11] for 2015 throughput at EWR, the projected 29.4% increase in operations per hour would result in a total of 529,389 operations and incidental (both aeronautical and non-aeronautical) airport revenue \$1.4 billion (Figure 9). The percent revenue increase from predictive density and wind-based spacing compared to static Phase I/II revenue added to yearly infrastructure expenses demonstrates that the implementation of dynamic spacing equipment at Phase III-compatible airports is a worthwhile investment.

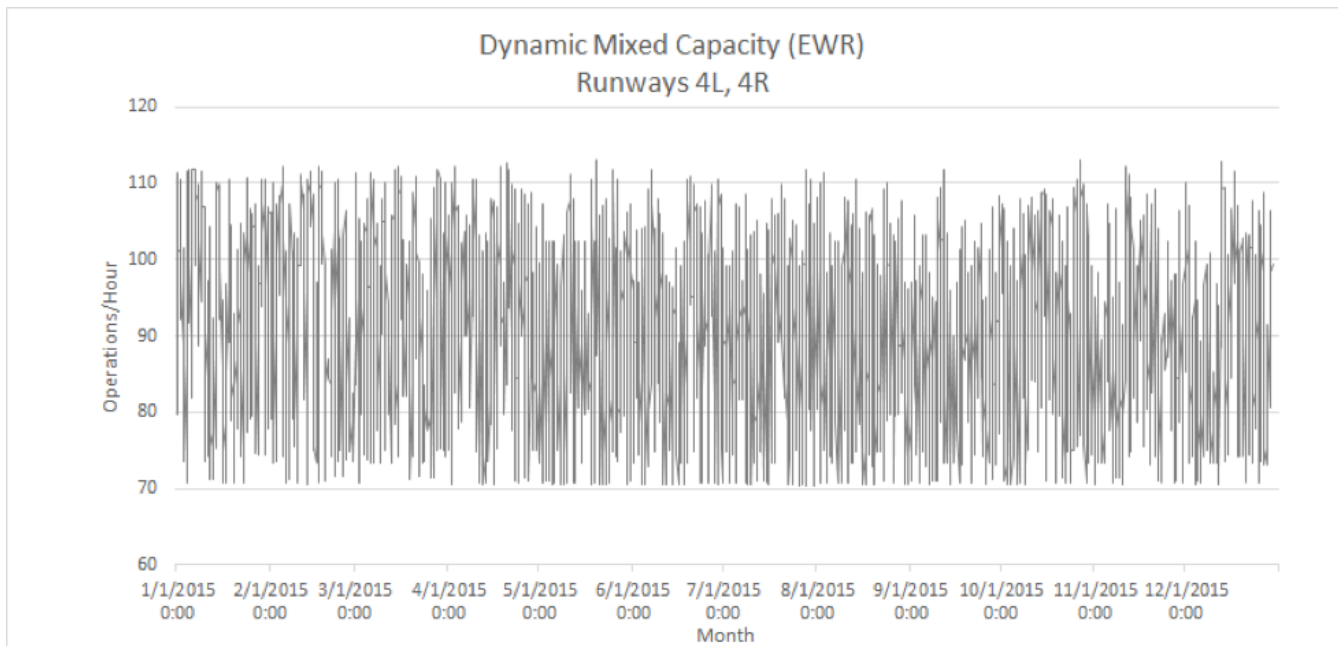
**LIMITATIONS**

**RDD VARIABLES**

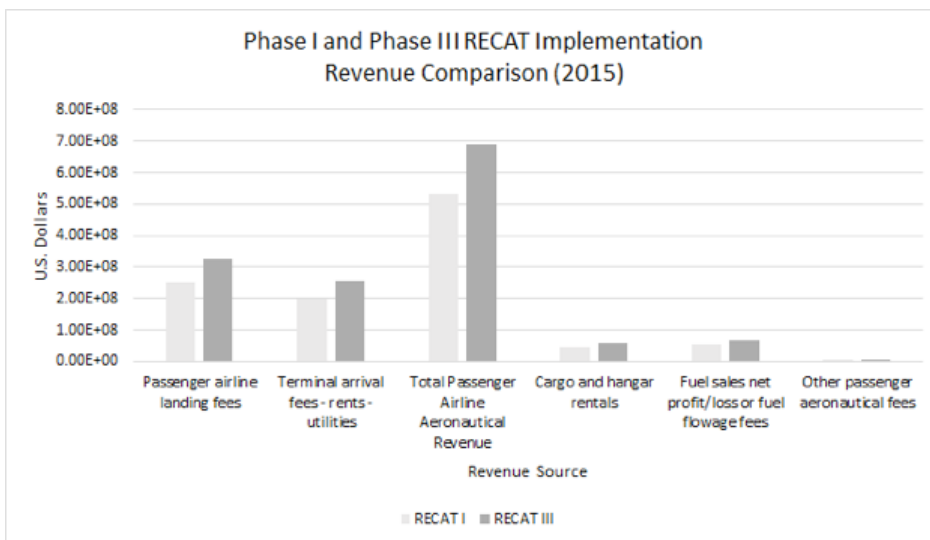
Wind data used in this model does not account for gusts or wind shear. Minimized wake turbulence separation distances due to dynamic readings operates under the assumption that weather conditions will remain at nearly the same state for the duration of the trailing aircraft's approach or departure procedures. Rapid changes in wind velocity can affect the distribution of wake vortices unpredictably and impact aircraft safety before action can be taken by the trailing aircraft to extend its separation. Air density is measured at the surface and assumes a standard lapse rate for temperature (1.98 °C / 1,000 ft) and air pressure (1.08" Hg / 1000 ft). Wind and air density, while major factors of wake vortex movement and dissipation, are only two atmospheric variables that can affect wake turbulence. Weather conditions, atmospheric turbulence and unstable pressure or temperature lapse rates can affect dissipation as well.

**CONTROL AIRCRAFT**

The RDD fluctuates rapidly with a small change in weight when using Eq. (3). As a result, category A and B control aircraft RDD inputs use experimental data rather than the RDD equation [12]. The fleet mix also represents a limited group of aircraft (one aircraft for categories A-D) compared to Phase II average and Phase III dynamic fleet mix measurements.



**Figure 8.** Simulated dynamic mixed capacity at EWR for runways 4L and 4R. Model mixed capacity projections yield a significant increase in aircraft throughput and airport revenue.



**Figure 9.** Phase I and Phase III Post-RECAT implementation revenue comparison. All airport revenue sources are directly proportional to aircraft throughput.

### MODEL SEPARATION DISTANCES

For distances defined in both the control and dynamic separations tables, the model assumes a constant landing roll duration of 60 seconds. Separations based on crosswinds rely on static initial vortex circulation strength values (regardless of atmospheric-induced dissipation intensifying with time) and a linear displacement of vortices matching crosswind velocity. Finally, crosswind

velocity is taken from ASOS data, which reflects surface winds only and may not accurately reflect wind conditions at different altitudes on approach beginning at the location where ATC authorizes RECAT spacing for trailing aircraft. For example, an aircraft on a curved area navigation (RNAV) approach path may encounter different density and wind direction values at its final waypoint than those detected by dynamic wake turbulence measurement

devices at the airport surface. This can result in an inconsistent flow of wake vortex turbulence from the leading aircraft through the atmosphere to the trailing aircraft and affect control of the trailing aircraft unpredictably.

## EXTERNAL IMPACTS

### GBAS AREAS OF CONCERN

Encounters with wake turbulence before established separation distances can be fatal. A dynamic model highlights further concerns brought about by the future implementation of Ground-Based Augmentation Systems (GBAS) at EWR and other U.S. airports which allow curved, stacked, and continuous-descent approaches out of current ILS localizer and glideslope ranges. High density air coupled with high wind conditions can create problems for any instance when a plane flies near the path of the other. In a parallel, independent approach scenario for runways 4L and 4R, a West-bound crosswind can direct the wake vortices from the 4R-inbound aircraft approach path to the 4L path. High density conditions minimize vortex encounters until short-final and low approach speeds. A predictive model should be used in order to prevent wake turbulence accidents caused by atmospheric effects

on vortex direction and dissipation rate.

### PHASE III TECHNOLOGY

#### LiDAR

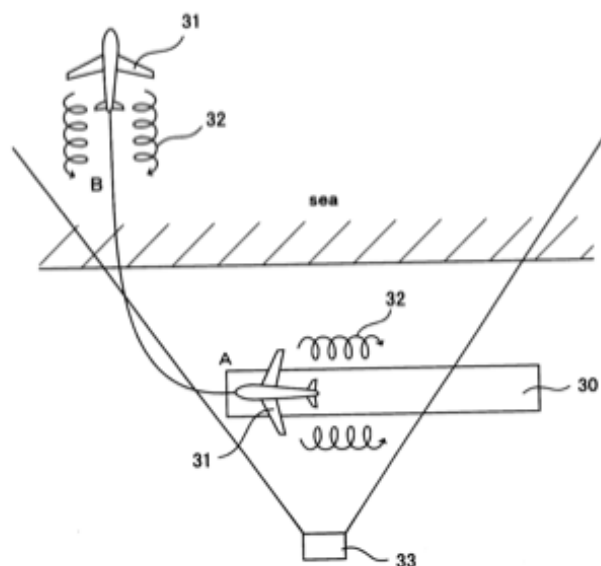
A Light Detection and Ranging system, also known as LiDAR, is a crucial technology for future research and development in the FAA RECAT program. LiDAR emits infrared light pulses into the atmosphere and measures the time it takes for light to travel back into the sensor after reflecting off of the dust particles in the air. By calculating the time traveled and comparing the frequency of the transmitted and received light, LiDAR is able to provide wind velocity data and other information relevant to the strength and behavior of wake turbulence [13]. It can also detect hazards such as wind shear from far away and provide information necessary for air traffic controllers to warn pilots of potential conflicts outside of approach and departure paths. This technology, however, is not perfect. It works best under clear and dry air, so the system would need to be complemented by traditional weather radar, such as Doppler Radar [14].

#### DOPPLER RADAR

Unlike the transmission and relay of infrared light with LiDAR systems, Doppler radar uses microwave signals to analyze the effect of object's motion on the frequency of the returned signal. Doppler is generally unreliable for minor variations in wind speed, but can accurately detect spectrum spreads caused by large shifts in speed [15]. Doppler radar can be used in tandem with ASOS station instruments to more accurately detect wind changes near the surface.

#### DETECTION HOTSPOTS

Another task that Phase III implementation faces associated with particle detection equipment is infrastructure placement on the airfield in such a way that all near-field wake turbulence hazard areas are included in vortex detection. Radar blind spots prevent vortex detection outside of the approach and departure flight paths parallel and in-line with the runway. As a result, one system design seeks



**Figure 10.** A diagram depicting strategic placements of detection hotspots to track areas where aircraft remain susceptible to wake turbulence at low altitudes. Aircraft A may intercept aircraft B's vortices on departure [17].

to emit a laser beam from two radars placed in different areas on the airfield to capture turbulence from crosswind and downwind flight paths (Figure 10) [16]. A signal processing device ensures that the radar observations do not overlap each other, and the larger wake turbulence decay times are reported in the form of dynamic separation distances to the controller.

### FUTURE RESEARCH

#### ATMOSPHERIC VARIABLES

The predictive model will always have capacity for more atmospheric variables and higher sampling rate. Currently, the ASOS samples hourly and only two dynamic variables are measured: crosswind components perpendicular to the flight path of the trailing aircraft and air density data based on stable temperature and pressure lapse rates. In future models, the effect of the vertical component on the spread and intensity of wake leading wake vortices will be taken into account. Vertical component measurements are imperative for approaches or departures behind leading aircraft which have made a crosswind turn. Increased weather technology, especially at different altitudes along flight paths within vicinity of the airport, will factor the effect of unstable lapse rates, gusts, and

wind shear into predictive vortex RDDs.

#### FLEET MIX

The predictive model currently uses a fleet mix of four aircraft in each weight category A-D. An enhanced model would accommodate a larger fleet mix of individual aircraft types in use during the year for capacity predictions. An optimal model would correlate certain fleet mixes with time of year (e.g., seasons) to increase fleet mix accuracy. Finally, the RDD equation used for the dynamic separations table should be modified using more experimental data to accommodate aircraft above Category B ( $RDD \geq 10,000$  m). Using takeoff and landing roll times, an enhanced model would replace constant in the opening and closing case capacity formulas with a time-based variable.

### CONCLUSIONS

The current state of wake turbulence recategorization can be further improved using dynamic vortex measurement technology. While research is still ongoing and initial testing of particle detection equipment is not expected until 2020, it is necessary for airports to determine how the technology will impact current capacity, safety, and revenue. This paper provides the backbone framework for



**Figure 10.** Aerial photo of the EWR airport terminal. Newark Liberty airport is helping pioneer the implementation of FAA's NextGen program in US airports [18].

predictive modeling of FAA Phase III Recategorization based on crosswind and air density measurements. The results for 2015 EWR modeling returned a substantial increase in capacity and revenue compared to static capacity data. Dynamic spacing distances were greatest between the months of March and November, when air density is low. A quadratic relationship between aircraft weight and RDD allows users of the predictive model to confidently estimate separation distances for aircraft types which have not been monitored by vortex detection equipment. Safety as a consideration for Phase III technology increases with the integration of GBAS technology at airports globally. Future enhancements to the predictive model will include wind measurements at all altitudes of the approach where turbulence conflicts remain possible, unstable atmospheric data, and a larger fleet mix with probability percentages replaced by a database of airport flight operations and correlating aircraft type. ■

## ABBREVIATIONS

**ASOS:** Automated Surface Observation System  
**ASPM:** Aviation System Performance Metrics (database)  
**EWR:** Newark Liberty International Airport  
**FAA:** Federal Aviation Administration

**GBAS:** Ground-Based Augmentation System

**JFK:** John F. Kennedy International Airport

**LHR:** London Heathrow International Airport

**LiDAR:** Light Detection and Ranging (system)

**MEM:** Memphis International Airport  
**NextGen:** Next Generation Air Transportation System

**RDD:** Required Decay Distance

**RECAT:** FAA Wake Turbulence Recategorization Program

**RNAV:** Area Navigation

**SFO:** San Francisco International Airport

**WTMA:** Wake Turbulence Mitigation for Arrivals

**WTMD:** Wake Turbulence Mitigation for Departures

## ACKNOWLEDGMENTS

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- [18] EWR Aerial Image. Photograph. Skidmore, Owings & Merrill LLP, www.som.com/projects.

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# Synthesis of Biodiesel from Hydrolyzed Rice By-Products Fermented with Engineered *B. subtilis*

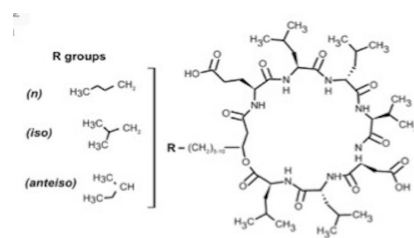
TARYN IMAMURA, STANFORD UNIVERSITY

Current methods of biodiesel production are not cost competitive when prices of crude oil are low. This study proposes a biodiesel production method that produces surfactant as a coproduct, making it profitable even when oil wholesale prices are low. In this study, Arkansas-grown rice hulls were hydrolyzed and fermented with genetically-engineered *B. subtilis* bacteria to produce FA-Glu surfactant. The FA-Glu was treated with 6M HCL and heated at 100°C until the surfactant separated into its oil and amino acid components. After separation, a hexane extraction was performed to make the oil easier to collect. The oil layer was extracted using a pasteur pipette, the hexane was evaporated, and the mass of the oil was measured and found to be 0.110g. The amino acid layer was analyzed through a glutamate assay to determine if the predicted reaction occurred by testing for the presence of glutamate, the byproduct of the FA-Glu separation. The assay showed a significant amount of glutamate showing the predicted separation did take place. According to NREL publications, this oil can be processed with a hydro-treatment to remove the oxygen atoms from the fatty acid, making it chemically indistinguishable from petro-chemical-derived diesel fuel.

## INTRODUCTION

In 2013, the National Renewable Energy Laboratory (NREL) published a process design and economic study aimed at using fermentation to convert cellulosic sugar into diesel fuel [1]. The report called for the development of a fermentation process that would enable production of diesel fuel from cellulosic sugar at a cost of \$5.00 per gallon in 2017 and \$3.00 per gallon in 2022. At the time that study was published, diesel fuel was selling at a wholesale price of \$3.00 per gallon. Today, diesel fuel sells at a wholesale price of \$0.98 per gallon. Given the low price of petrochemical derived diesel fuel, there is a need for a method of cost effective production of bio-diesel (K. Jarrell, personal communication, January 20, 2015). This study describes a process that has the potential to enable profitable production of bio-diesel by fermentation, even when the price of petrochemical derived diesel is very low. The process allows a manufacturing facility to modulate the relative amounts of bio-diesel and higher value chemical products (surfactants) produced to ensure the factory operates with a consistent profit margin, even as the price of diesel fluctuates.

A surfactant is a substance that, when dissolved in a liquid, reduces the surface tension of that liquid [2]. Biosurfactant (surfactants produced by living organisms) were first discovered by Arima, Kakinuma, and Tamura in 1968. This substance was naturally produced by several strains of *B. subtilis* bacteria [3].



**Figure 1.** Structure of surfactin [2]. (FA-Glu) [4].

The use of genetically-engineered *B. subtilis* to generate surfactant has been pursued, especially in recent years, by commercial labs such as Modular Genetics, Inc. because it allows for the manufacturing of surfactants from renewable agricultural by-products such as rice, soybean, and cottonseed hulls [4]. Feed stocks such as these are the preferred raw materials for the bioproduction of chemicals and fuels because the carbohydrates derived

from their cellulosic material are not processed to generate food and cellulosic carbohydrate is the most abundant form of carbohydrates on earth [5], [2]. Furthermore, several techno-economic analyses have concluded that the production of chemicals and fuels from cellulosic material is sustainable when compared to current production methods [6], [7].

Rice hulls which were the media used in this study are a waste product and would not compete with food uses. Rice hulls could potentially provide a greater net energy gain than the use of corn stover or soybean hulls because, as a waste product, rice hulls do not require the additional energy put into the production of feedstocks. Additionally, the rice hulls used in this study have few other uses. They are also easily accessible, renewable, and, most importantly, inexpensive. Arkansas is the largest producer of rice hulls in the nation, producing approximately 48% of the total production of rice and rice hulls [8].

Fatty-acyl-glutamate (FA-Glu), the surfactant produced in this study, is structurally similar to surfactin in that it is composed of  $\beta$ -hydroxy fatty-acid chains containing 12-17 carbons.



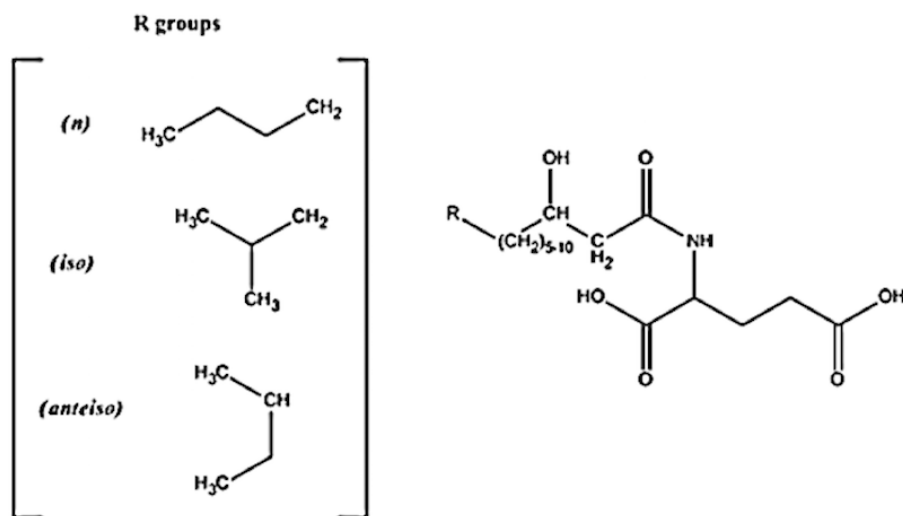


Figure 2. Structure of fatty-acyl-glutamate (FA-Glu) [4].

However, unlike surfactin, the fatty-acid chains in FA-Glu are linked by an amide bond to a single glutamic acid residue (see Figure 2). FA-Glu lacks the heptapeptide moiety of surfactin, having only one of the seven amino acids found in surfactin (i.e., glutamate) [9], [4]. Because of these structural differences, FA-Glu is more water soluble and thus more effective when dissolved in a liquid than surfactin [9].

The structure of FA-Glu implies that it is possible to separate the molecule into its amino acid and fatty acid chain by breaking the amide bond with the use of a strong acid (see Figure 2). The resulting fatty acid chain could be processed to produce a biodiesel, analogous to way that soybean biodiesel is produced. Based on this information, it was hypothesized that an oil that could be converted into biodiesel could be produced by cleaving the FA-Glu produced by *B. subtilis* bacteria at its amide bond.

## PROCEDURES

### PREPARATION

Arkansas-grown rice hulls donated by Riceland Foods in Stuttgart, Arkansas were ground using both a commercial blender. The ground rice hulls were sieved and the particles whose sizes were between approximately 1 mm and 0.45 mm were collected. Approximately 400 g of the 0.45 mm rice hulls that were mixed with 200 g of rice hull powder that was ground by Microgrinding Inc. in Little Rock, Arkansas. The

remainder of the Microgrinding rice powder was mailed via UPS overnight shipping to Modular Genetics Inc. in Woburn, Massachusetts to be processed into hydrolysate using more varied conditions in addition to the conditions tested by the researcher. Next, 4 L of 0.1 M  $\text{CH}_2\text{COONa}$  was mixed and the pH was adjusted to approximately 5 using glacial acetic. Then, 1 L of the mixture was added to 150 g of the ground rice hull mixture in 1 L bottles and the contents were mixed. The samples were sterilized in an autoclave at  $121^\circ\text{C}$  and 18 psi for approximately 1 hr.

### ENZYMATIC DIGESTION

After the samples cooled, they were treated with an enzymatic hydrolysis to digest the complex polysaccharides of cellulosic material into mono- and disaccharides that the *B. subtilis* could more easily convert into surfactant. For this hydrolysis, 5.1 g of cellulase

from Flinn Scientific was added to each of the 0.5 L samples. The corresponding samples were combined, mixed, and halved into a sterile 1 L Erlenmeyer. The flasks were incubated in a MaxQ Mini 4450 shaking incubator at  $50^\circ\text{C}$  at 200 rpm for approximately 24 hr. After incubation, the samples were centrifuged at 4400 g for 10 minutes at  $20^\circ\text{C}$  to separate the liquid from the solid cellulosic material and the pH of the supernatant was adjusted to approximately 7.5 using 5 M NaOH.

### CARBOHYDRATE QUANTIFICATION

Next, the samples were taken to Modular Genetics in Woburn, Massachusetts. To maintain the quality of the samples, they were frozen and mailed overnight the lab on ice.

The samples were filter sterilized using  $0.45\ \mu\text{m}$  filters and stored at  $4^\circ\text{C}$  until they were analyzed. The most suitable samples were determined through a carbohydrate assay. First, a serial dilution of glucose between  $10\ \mu\text{g}/\text{mL}$  and  $200\ \mu\text{g}/\text{mL}$  was made to act as the standard curve in the quantification.

Table 1. Standard dilutions used to generate the standard curve for the carbohydrate assay and their optical densities at OD 490.

Standard dilutions	OD490
0	0
10	0.1301
25	0.2658
75	0.4952
100	0.8163
150	1.2391

### Optical Density vs. CHO

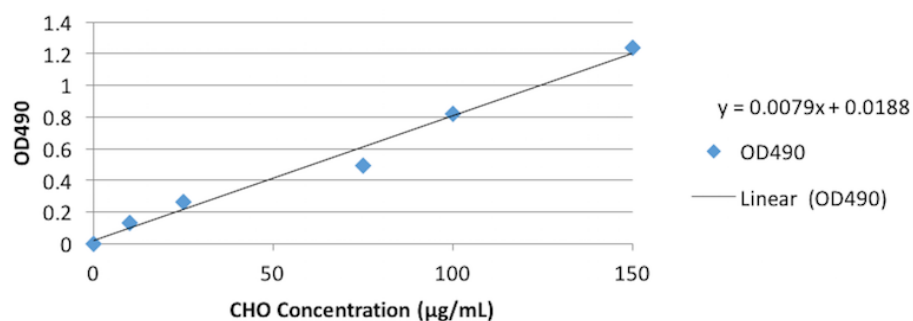


Figure 3. Standard curve used to analyze that amount of carbohydrates (CHO) in the winning hydrolysate condition.

Sample	OD490	$\mu\text{g CHO}$	dilution	Adjusted g/L CHO
Enzyme	3.0225	380.2	1000	380.2
Mixed with Flinn 1	0.975	121	250	30.3
Mixed with Flinn 2	0.7603	93.9	250	23.5
Mixed with Flinn 3	1.0117	125.7	250	31.4
Mixed with Flinn 4	0.9189	113.9	250	28.5
Ground with enzymes	1.1138	138.6	250	34.7
Very Finely ground	2.1838	274.1	250	68.5

**Table 2.** Optical density at OD 490,  $\mu\text{g CHO}$ , dilution, and adjusted CHO in g/L of the hydrolysate conditions.

M9YE media components	g of components per liter
yeast extract	3 g
dibasic sodium phosphate	6 g
ammonium chloride	1 g
Monobasic potassium phosphate	3 g
Sodium chloride	0.5 g

**Table 3.** Composition of M9YE growth media.

Parameter	Setting
Media	S7 (Phos 7.5) (2% hydrolysate)
Volume	3L (including 840 mL hydroly-)
Aeration	3 standard cubic feet/hour
Temperature	37C
Agitation	200 RPM

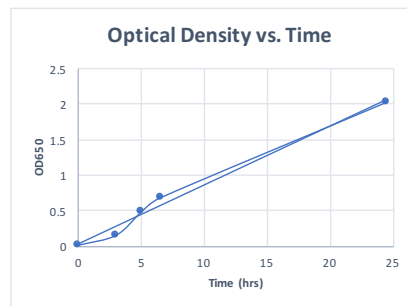
**Table 4.** Fermentation settings for the best rice hydrolysate condition. Throughout the fermentation period, samples were collected from hydrolysate and analyzed using spectrophotometry.

Time	OD650
0	0.0234
3	0.1632
5	0.4902
6.5	0.6892
24.5	2.034

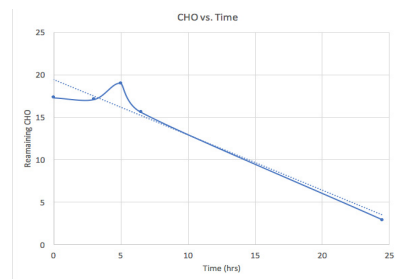
**Table 5.** Optical density for the BioFlo fermentation culture as a function of time.

Time	Remaining CHO (g/L)
0	17.3
3	17.1
5	19
6.5	15.6
24.5	2.9

**Table 6.** Carbohydrate concentration data for BioFlo fermenter as a function of time.



**Figure 4.** Optical density vs. time (hours) for the BioFlo fermentation at OD650.



**Figure 5.** Remaining amounts of CHO in g/L vs. fermentation duration in hours.

All hydrolysate samples were diluted to fall within this linear range. Next, 500  $\mu\text{L}$  of a water blank and all the standards and unknowns were added to glass culture tubes and, under a hood, 500  $\mu\text{L}$  of 5% phenol and 2.5 mL of 18M sulfuric acid were added to all tubes. The samples were cooled for approximately 15 min before 1 mL of each sample was pipetted into a clean cuvette and the carbohydrate content was measured at OD490. The results of the process are shown below (see Table 1, Table 2, and Figure 3).

Table 1 shows the standard dilutions used to generate the carbohydrate (CHO) calibration curve shown in Figure 3. The standard curve was created using known concentrations of glucose,

the spectrophotometer readings were plotted, and Excel was used to generate a trend line and equation to best fit the numbers. This equation was used to calculate the unknown CHO concentrations of hydrolysate from the spectrophotometer readings (see Table 2). These values were multiplied by the dilution factor to get a g/L of CHO and the CHO concentrations were multiplied by the volumes of either hydrolysate or enzyme to get mg CHO for the whole sample (see Table 2). Because the enzymes were originally added to the hydrolysate, the mg CHO from the enzyme was subtracted from the hydrolysate to get only the CHO produced from the hydrolysate as shown in the adjusted g/L CHO column. This adjusted value was used to figure out the conversion of hydrolysate into CHO.

This process was done to the hydrolysate samples produced at Modular and at the Arkansas School for Mathematics, Sciences, and the Arts (ASMSA) to determine which hydrolysate contained the most sugar content for the bacteria. It was determined that the hydrolysate made from the finely ground hull powder was most suitable for fermentation with the *B. subtilis* bacteria because it contained the highest concentration of glucose for the bacteria.

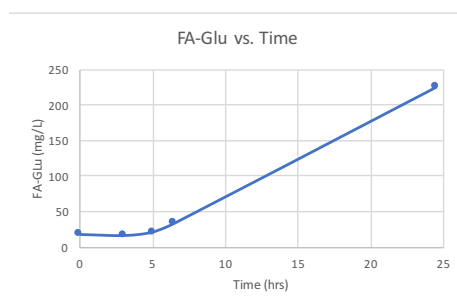
### BioFlo FERMENTER

A seed culture of genetically-engineered *B. subtilis* bacteria was grown in 150 mL of M9YE 0.5% glucose growth media. The components of the M9YE growth media are shown in Table 3 with their amounts in g/L.

The media was inoculated with the bacteria and incubated at 30° C. After the seed culture was grown, the culture was analyzed using spectrophotometry and was found to have an OD of 1.67. The winning hydrolysate condition was inoculated with 60 mL of the genetically-engineered *B. subtilis* bacteria from the seed culture and fermented for 25 hours (see Table 4 for conditions).

Table 5 and Figure 4 show the optical density at 650 vs time the samples were fermenting. The optical density of the samples increased as

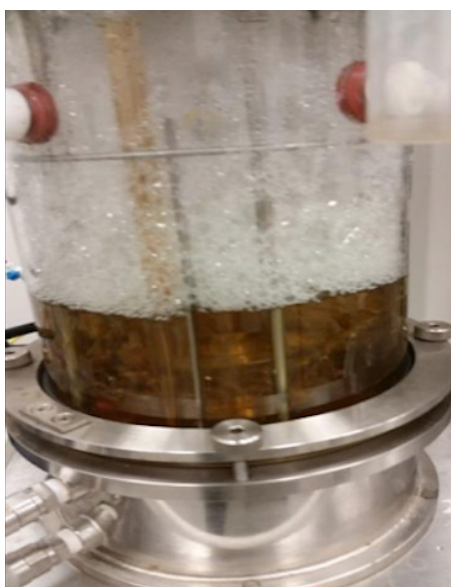
progressed (see Figure 4). This increase in optical density implies an increase in matter present in the sample and occurred because of the *B. subtilis* bacteria breaking down the glucose present



**Figure 6.** Amount in mg/L of FA-Glu surfactant produced by the bacteria during the fermentation period. It should be noted that, although the bacteria died prematurely as a result of aeration blockage in the BioFlo apparatus, the total yield of surfactant was adequate for the purposes of this study.

Time	FA-Glu (mg/L)
0	17.9
3	16.5
5	21.4
6.5	34
24.5	225.5

**Table 7.** FA-Glu concentration in the BioFlo fermenter as a function of time.



**Figure 7.** BioFlo fermenter with the foam and media layers of the fermentation inside of it.

in the hydrolysate. The information from Table 4 and Figure 4 was used to calculate the amount of CHO remaining in the samples as they were fermented (see table 6 and Figure 5 for this data).

Table 6 and Figure 5 show the amount of CHO remaining in the samples after being fermented with the *B. subtilis* bacteria for 25 hours. The data in these figures was determined from the OD650 vs. time data and the carbohydrate assay performed after the samples had been fermented. Table 6 shows that, as the hydrolysate was fermented with the bacteria, the bacteria consumed the carbohydrates present in the hydrolysate as predicted. Tables 5 and 6 were generated to show that the *B. subtilis* bacteria were behaving as predicted throughout the fermentation process and were completing the chemical and reproductive processes that would enable them to produce viable amounts of FA-Glu surfactant.

The amount of surfactant produced throughout the process was determined from samples collected throughout the fermentation process and calculated using LCMS. The amount of FA-Glu produced in mg/L and the time at which the reading was taken are shown in Table 7 and Figure 6.

Table 7 and Figure 6 show the amount of FA-Glu surfactant produced by the *B. subtilis* as the rice hull hydrolysate was fermented. The surfactant was split into two sample groups shown in Figure 7: surfactant collected from the foam of the fermentation and surfactant collected from the liquid media.

It should be noted that, between hour seven and 25 of the fermentation, the BioFlo Apparatus' aeration tube became clogged, blocking the O<sub>2</sub> supply. As a result, the bacteria died before they could finish producing surfactant. Despite this malfunction, a total volume of 80 mL of FA-Glu was collected from the foam samples and 2.88 L from the liquid media samples.

### SURFACTANT ISOLATION

The media fermentation samples were centrifuged at 8200 g and 21° C for 30 min. The foam samples were centrifuged at 5000 g and 25° C for 10 min to remove the cells from the samples and decanted into a reaction tube. The media samples were centrifuged again at the same settings for

an additional 10 min and decanted into two 2 L. To separate the surfactant from the liquid portions of the foam and media samples and solidify it, the two media samples and foam fraction were acidified with 28 mL, 30 mL and 1.4 mL 12 M HCL respectively. The acidified media was stored at 4° C for about three days.

The samples were retrieved from storage and the media samples were centrifuged at 8200 g and 20° C for 30 min to separate the precipitated surfactant from the media liquid. The foam samples were centrifuged at 5000 g for 10 min. The liquid from both sample types was decanted and the solid pellet was kept and stored at 4° C.

### FA-Glu ACIDIFICATION

The solid media pellets from half of the media samples were scraped into conical tubes and 1.25 mL of 6 M HCL was added. The samples were halved so that another trial could be attempted if the first attempt to cleave the surfactant into oil and amino acids failed.

The Foam 1 and Media 1 samples were placed in an oven at 100° C and checked regularly for signs of separation. After approximately 3.5 hr, there did not appear to be a significant amount of separation. This lack of separation was assumed to have been caused by the FA-Glu still being wet when the HCL was added. As a result, the acid was more dilute than intended and did not cleave the FA-Glu as expected. The Foam 1 and Media 1 samples were left in the oven to continue the reaction while the Foam 2, Media 2, and a pure FA-Glu control were prepped to be cleaved in the oven.

For the second trials, the initial conditions were adjusted to account for the wet weight of the FA-Glu in the Media 2 and Foam 2 samples. For the second trial, 8 mL of 6M HCL was added to the pure FA-Glu control because of its lack of moisture in its crystalline form while 4 mL of 12 M HCL was added to the Media 2 and Foam 2 samples to account for their moiety. The samples were mixed and placed in an oven at 110° C for 1 hour.

After one hour, the samples were once again retrieved and inspected. The separation of the Foam 1 and Media 1 samples appeared to be more distinct; however, because of the excess particle matter in the tubes it was difficult to tell.

## HEXANE EXTRACTION

Because of an excess of particulate matter, which most likely consisted of denatured proteins, a hexane extraction was conducted to make the separation between the oil and amino acid layers of the samples more distinct.

First, the samples were retrieved from the oven and 1 mL of hexane was added to the control sample first to act as a test run because more purified FA-Glu crystals were available for additional trials while more of the media and foam samples were not.

The control sample was mixed and, upon visual inspection, the oil began to separate almost instantly. This process was repeated with the two foam and two media samples. The samples were examined against a white background for signs of separation. From initial observations, the Foam 1 sample exhibited the most separation between the oil and aqueous layers (See Figure 8).

## GLUTAMATE ASSAY

Analysis of the oil produced would have required a gas chromatography mass spectrum or GCMS. However, access to a GCMS equipment was not available. Because the oil itself could not be studied, a glutamate assay was used to analyze the aqueous byproduct of cleaving the FA-Glu. When the FA-Glu was cleaved on its amide bond, it should have split into two components: a fatty acid chain (oil) and an aqueous layer that contained denatured amino acids and glutamate. The glutamate assay was conducted on the aqueous layers of the Foam 1, Foam 2, Media 1, Media2, and control samples to confirm the predicted reaction had occurred and quantify the amount of oil produced from the acid treatment.

To perform the glutamate assay, an Enzychrom Glutamate Assay Kit (EGLT-100) was used. First, the glutamate standards from the kit was thawed and used to generate a glutamate serial dilution (see Table 9 for the data). All dilutions in the serial dilution were kept at a volume of 100  $\mu$ L.

A premix from the kit was made by pipetting 15  $\mu$ L of 100 M glutamate standard into 585  $\mu$ L of distilled H<sub>2</sub>O

and the premix was mixed using a Vortex Genie. The foam and media samples and control were diluted 1:100 by pipetting 5  $\mu$ L of the aqueous layer and adding it to 459  $\mu$ L of distilled H<sub>2</sub>O. The glutamate assay involved a time sensitive reaction and took data from the samples in two readings, one at the beginning of the reaction and one 30 min later. To start the reaction, the premix and a reaction catalyst were pipetted into the tubes with the dilutions. The dilutions were mixed, pipetted into a quartz cuvette, and analyzed using a spectrophotometer. The samples was pipetted back into its tube and the cuvette was rinsed with distilled H<sub>2</sub>O in preparation for the next dilution because only two quartz cuvettes were available. The data collected from the first and second reading was entered into an equation supplied by the assay kit and graphed using Excel.

## DATA ANALYSIS AND RESULTS

Table 11 and Table 12 show the data collected from the glutamate assay at two times. The data from these two tables was entered into the equation provided by the glutamate assay kit to calculate that data shown in Table 12 and Figure 9.

The data from the standard curve was used to calculate the concentrations of glutamate present in the dilutions.



Figure 8. Separation of the amino acid (bottom) and oil (top) layers.

These concentrations were then converted into amounts and recorded in Table 12 to be analyzed.

The Foam 1 samples, contained the second highest concentration of glutamate (see Figure 9). This was expected as the Foam 1 sample was the rice hydrolysate sample that exhibited the most significant amount of separation between the oil and glutamate layers. However, while the

Dilution	Premix ( $\mu$ L)	H <sub>2</sub> O ( $\mu$ L)
1	100	0
2	80	20
3	60	40
4	40	60
5	30	70
6	20	80

Table 8. Components and amounts for the serial dilution made from the glutamate kit. Note that all samples in the dilution were kept at a volume of 100  $\mu$ L.

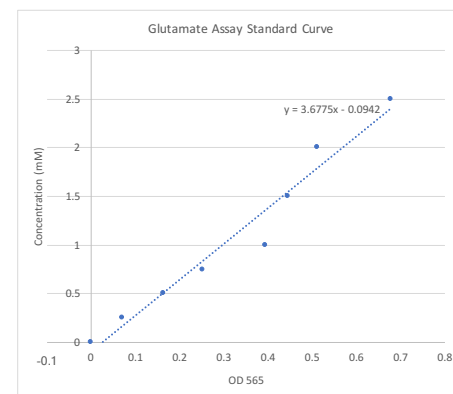


Figure 9. Calibration curve generated by Excel for the glutamate assay.

Standards	OD 565	Samples	OD 565
0	0	control	0.0164
2.5	0.1542	media FA-	0.2619
2	0.1896	Media FA-	0.0005
1.5	0.0259	foam Fa-glu 1	0.0104
1	0.0805	foam Fa-glu 2	-0.0473
0.75	0.0132		
0.5	0.006		
0.25	-0.167		

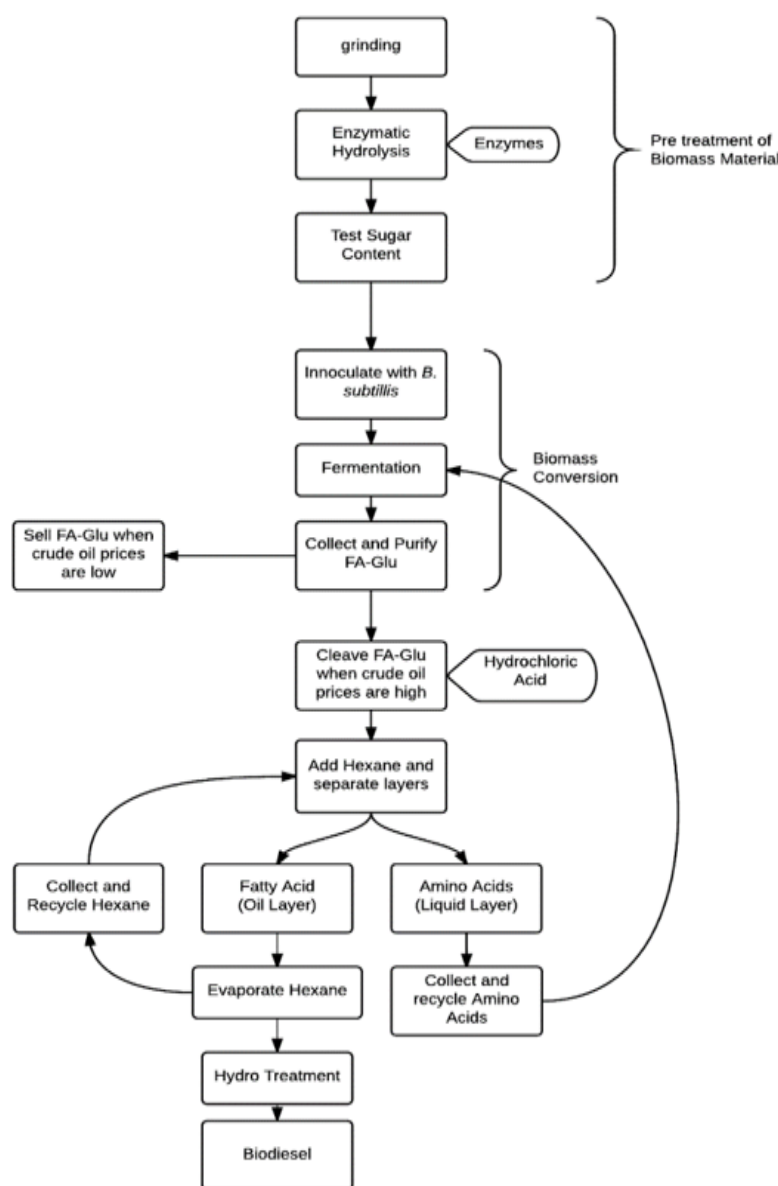
Table 9. Spectrophotometry data from the first reading of the glutamate assay for the standard curves and the foam, media, and control samples.

mM glutamate	OD 565
0	-0.0007
0.25	0.071
0.5	0.1637
0.75	0.2527
1	0.3941
1.5	0.4463
2	0.511
2.5	0.6781

**Table 11.** Concentration (in mM) of glutamate for the standard curve shown in Figure 10 and the optical density of that dilution at OD 565.

Sample	mg/L glu
Control	9.21
M1 aqueous	215.98
M2 aqueous	6.88
F1 aqueous	52.18
F2 aqueous	30.82

**Table 12.** Glutamate present in the samples as calculated from the standard curve in Figure 9.



**Figure 11.** Flow chart generated by the author that summarizes the biodiesel production method as it is described in this study.

control samples should have contained the highest concentration of glutamate, assay data showed it contained one of the lowest concentrations with an amount of 9.21 mg/L of glutamate. After further analysis, it was determined that, due to the time sensitive nature of the reaction and the recursive nature of the calculations, the glutamate assay was unreliable for statistical analysis and glutamate quantification.

However, the assay did show that each sample created some glutamate during the FA-Glu separation. The presence of significant amounts of glutamate in all the samples clearly shows the predicted reaction occurred as hypothesized.

The oil produced in this study is a fatty acid chain, which is an oil that also contains oxygen atoms. According to the 2013 NREL document, if this oil were to be processed with a hydro treatment, it would be chemically indistinguishable from petro-chemical-derived diesel fuel. Although NREL cited this as the next procedure in the biodiesel process, they did not test it as the hydrotreating technology and process already exist and are well known. The entire process described in this study is depicted in the flow chart as it would be applied in a facility that produced surfactant and biodiesel via this method.

## CONCLUSION

It was hypothesized that an oil could be produced by cleaving the FA-Glu produced by *B. subtilis* bacteria on its amide bond. This hypothesis was supported by the visible oil separation in Figure 8 and the glutamate assay that showed significant amounts of glutamate, the waste product of the predicted chemical process, were present in the amino layer of the samples. The oil synthesized in this study is structurally similar to biodiesel and, according to a 2013 study conducted by NREL, if the O<sub>2</sub> molecules present in the fatty acid were replaced with hydrogen through hydrotreatment, a process that has been well-known since the 1930's and 1940's, then the resulting substance would be structurally indistinguishable from biofuel [1].

This study was inspired by the 2013 NREL process design and economic

study; however, the process described in this study improves upon the NREL model because it possesses the potential to be profitable independent of oil price fluctuations. The major limitation of the facility proposed by NREL is that their process was not economically feasible at the time due to low wholesale oil prices. By contrast, the process described in this study is market-price-independent because it produces biodiesel as a coproduct to biosurfactant. FA-Glu surfactant can be sold at a price of \$2.00 per unit (K. Jarrell, personal communication, January 20, 2015). By adjusting the ratio of surfactant sold relative to the amount of biodiesel sold, a facility producing biodiesel via this method could be assured to profit regardless of price fluctuation in oil by producing more FA-Glu when diesel (and crude oil) prices are low and less FA-Glu when diesel (and crude oil) prices are high. Additionally, the amino acid layer created as a by-product of cleaving the FA-Glu could be purified and sold for a profit or recycled back into the fermentation process as a raw material.

This study was limited by the small scale of experimentation, relatively short duration of experimentation, and by the lack of equipment. In order to properly analyze that oil synthesized in this study, the oil would have had to have been analyzed using a gas chromatography mass spectrum or GCMS. Because access to a GCMS was not available, the glutamate waste created when the FA-Glu was cleaved had to be analyzed through a glutamate assay instead of the oil itself. These limitations could be remedied in future studies through access to more advanced equipment.

Several aspects contribute to the relevance of this study. The first is to provide a viable use for agricultural waste products such as the rice hulls used in

this experiment. In fact, for large-scale deployment of the technology described here larger quantities of cellulosic material (in addition to rice hulls) would be needed. Possible sources of cellulosic material include switchgrass, corn husks and, cottonseed hulls. An exciting aspect of this study is linked to the requirements of the facility that would utilize this process. For such a facility to be feasible, the hydrolysis of cellulosic material, fermentation of the hydrolysate, synthesis of biodiesel, and production of surfactant would have to occur in a facility near the source of the cellulosic materials used for the conversion. Because of this constraint, a facility would most likely need to be in Arkansas, thus creating jobs and potentially a new industry in my home state. ■

### ACKNOWLEDGMENTS

This project would not have been possible without the help of Modular Genetics Inc. Specifically, Taryn would like to thank Dr. Kevin Jarrell, Michelle Pynn, and Tony Tempesta for their mentorship and help in developing this research. Taryn would also like to thank Dr. Brian Monson for his help and support in this project and the ones leading up to it.

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## TARYN IMAMURA

Taryn Imamura is a sophomore at Stanford University and a research intern at the Stanford Linear Accelerator Center (SLAC). She is currently pursuing a degree in Engineering Physics with a focus in Electromechanical Systems Design and is minoring in Feminist, Gender, and Sexuality Studies. Her academic interests include particle physics, marine biology, robotics and creative writing. Her passions include mentoring young people and advocating for women's involvement in STEM. Imamura is originally from Conway, Arkansas, and she conducted her research with the goal of creating industry in her impoverished home state. She developed an economically-feasible process of biodiesel production that utilizes the agricultural waste products abundant in Arkansas. Her research is currently being used to obtain funding for a facility that would produce biodiesel via her proposed method.

# Testing the Turing Test in Late 2017

SIDHARTH VISWANATHAN, VELAMMAL ENGINEERING COLLEGE (CHENNAI)

In 1950, Alan Turing considered the question: "Can machines think?". The phrases "machines" and "think" are defined by the problem. In 2017, seven decades after Alan Turing proposed the question, we aim to test the "Turing test" on current available technology. There has been remarkable progress in hardware that utilizes machine learning. While GPUs have been a major driver of this recent progress, we want to know if a human and computer could pass the Turing test. Later on, we utilize this test to extend it to validate day-to-day applications, such as checking versatility of chat bots. In addition, through the process of proving the Turing test incorrect in certain situations, flaws in the system design and a misconception of ideas for the system built are exposed. Additionally, architectural defects in human-computer interactions are uncovered.

## OVERVIEW OF TODAY'S HARDWARE

There is a remarkable convergence of trends in applications, machine intelligence, and hardware, which increases opportunity for major hardware and software changes. With the progress of machine intelligence over seven decades, can the Turing test still be relevantly applied? More interestingly, will the Turing test results show that computers will eventually surpass humans?

The initial notion of this research is to focus on machine intelligence in the hardware of the early Babbage Machines all the way to premodern machines (preceding the internet) and modern multicore digital computers. The following notions qualify machines to be put under Turing test:

1. Machine evolution over any scale of time does not alter the correctness and legitimacy of the Turing test.
2. Hardware at any scale of time must obey the Turing test.
3. If hardware developed in the future does not deviate from the Turing test, then the hardware design is said to be flawed.
4. Machine learning hardware cannot veer the works of A.M. Turing [7] or the Turing test.

In the next few sections, we detail machine evolution and machine intelligence.

## MACHINE INTELLIGENCE IN HARDWARE

Neural network research has been controversial, going through a typical hype curve. The first neural network algorithm developed was a brain-inspired algorithm; however, capabilities were limited to performing linear classification, though multilayer perceptron was later shown to be capable of nonlinear classification. Towards the end of the 1980s and the beginning of the 1990s, such neural networks increased in efficiency, even leading to hardware neural network accelerators such as the ETANN from Intel. However, during that time, hardware neural networks had limitations, e.g. (1) the application scope of neural networks was fairly restricted; (2) the clock frequency of processors were not increasing quickly enough that an accelerator could be outperformed by a software neural network run on a processor after a few technology generations; and (3) competitive machine learning algorithms emerged, especially the support vector machine (SVM). Furthermore, Cybenko's theorem [2] stipulated that a neural network, which is a single hidden layer, could approximate any continuous function with

infinite precision, suggesting that deeper and larger neural networks would bring less valuable returns.

Still, researchers such as Yoshua Bengio, Geoffrey Hinton [5], and Yann LeCun [6] kept pushing the notion of neural networks in the community, and around 2006, neural network models with large and wide layers (along with a combination of auto-encoders), i.e., so-called deep neural networks (or DNNs), were shown to achieve competitive results on some applications against the state-of-the-art machine learning techniques. As GPUs started to allow the training of larger neural networks on larger training sets, the performance of these deep neural networks kept increasing; they have now consistently been shown to achieve state-of-the-

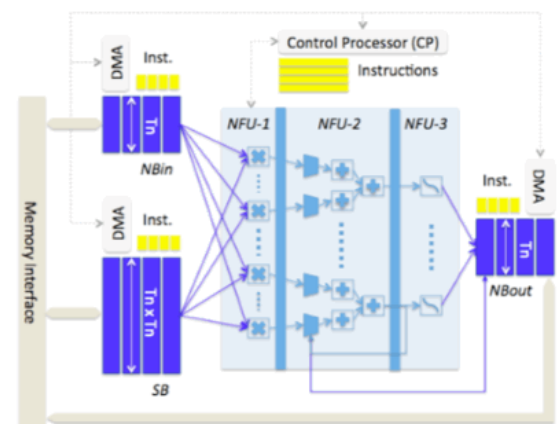
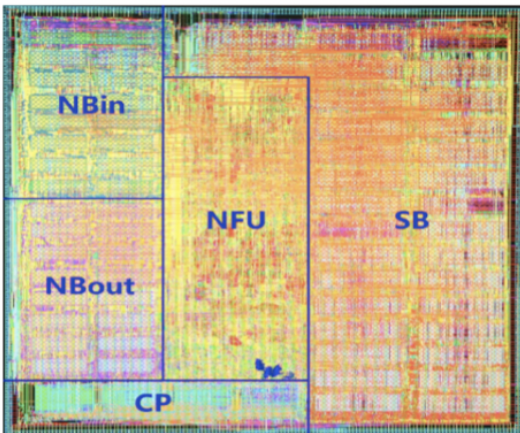


Figure 1. Hardware using machine learning



**Figure 2.** Hardware neural network accelerators

art performance on a broad range of applications.

There is a remarkable convergence of trends in applications of machine learning and hardware, which creates opportunities for hardware machine learning acceleration. As we mentioned in the previous section, deep neural networks have become state-of-the-art machine learning algorithms. In parallel, technology constraints have started to progressively initiate a shift towards heterogeneous architectures and hardware accelerators.

## FORMER WORKING OF A DIGITAL COMPUTER

The idea behind digital computers as digital hypothetical machines [7], from Alan Turing's research, is that they are intended to carry out any operations which could be done by a human computer. The computer is supposed follow fixed rules; it has no authority to deviate from them in any detail. We suppose that the rules to the digital computer are supplied in a book, which is altered whenever the computer is given a new job. It has also an unlimited supply of paper on which it does its calculations [7]. Digital computers can also do simple operations such as multiplication and addition on a "desk machine", or by using a supporting calculating machine for performing calculations. However, since digital machines should be made to perform all the complex calculations by itself, it should not use a supporting machine. It is apparent, then, that if we use the above explanation as a definition

for digital machines, we will be in danger of circularity of argument.

A digital computer can usually be regarded as consisting of three parts: (i) the store, (ii) executive unit, and (iii) control. The store is a repository of information and corresponds to the human computer's paper, whether it is the paper on which he does his calculations or that on which his book of rules is printed. In so far as the human computer does calculations in his head, a part of the store will correspond to his memory.

The executive unit is the part which carries out the various individual operations involved in a calculation. What these individual operations are will vary from machine to machine. Usually fairly lengthy operations can be done, such as multiplying 3540675445 by 7076345687, but in some machines only very simple ones such as printing 0 are possible. We have mentioned that the "book of rules" supplied to the computer is replaced in the machine by a part of the store. It is then called the "table of instructions". It is the duty of the control to see that these instructions are obeyed precisely and in the correct order. In contrast to modern machines, the storage size increases progressively over time. The execution unit is limited to the processor or a distributed server.

The information in the store is usually broken up into packets of moderately small size. In one machine, for instance, a packet might consist of ten decimal digits. Numbers are assigned to the parts of the store in which the various packets of information are stored, in some systematic manner. A typical instruction might read "add the number stored in position 6809 to that in 4302 and put the result back into the latter storage position". Needless to say, the instruction would not be expressed in English. It would more likely be coded in a form such as 6809430217. Here, 17 indicates which of various possible operations are to be performed on the two numbers. In this case the operation is that described above, viz., "add the number..." Notice that the instruction takes up 10 digits

and conveniently forms one packet of information. The control will normally take the given instructions in the order of the positions in which they are stored, but occasionally an instruction such as "now, obey the instruction stored in position 5606, and continue from there" may be encountered. Instructions of these types are very important because they make it possible for a sequence of operations to be replaced repeatedly until the condition is fulfilled. For a domestic analogy: suppose Tommy's mother wants Tommy to call at the cobbler's every morning on his way to school to see if her shoes are done. She can ask him every morning. Alternatively, she can just stick a note that asks him to call the cobbler in the hall which he will see when he leaves for school and then destroy the notice when he comes back with the shoes. Digital computers can be, and indeed have been, constructed in the same way. They can in fact mimic the actions of a human computer very closely.

The book of rules the human computer uses is, of course, a convenient analogy. Actual human computers remember their tasks. To make a machine mimic the behavior of the human computer in some complex operation requires asking it how it translates the answer into the form of an instruction table (what we call "programming"). To "program a machine to carry out the operation A" means to put the appropriate instruction table into the machine so that it will do A. An interesting variant on the idea of a digital computer is a "digital computer with a random element." These have instructions involving the throwing of a die or some equivalent electronic process; one such instruction might, for instance, be: "Throw the die and put the resulting number into store 1000." Sometimes, such a machine is described as having "free will". Most actual digital computers have only a finite store; however, there is no theoretical difficulty in the idea of a computer with an unlimited store. Of course, only a finite part can have been used at any one time. Likewise, only a finite amount can have been constructed, but one can add more as is required. Such computers have special theoretical interest and would be called infinite capacity computers. However, this has



been proven to be practically impossible. So, machines that are subjects in the Turing test can hold only a finite amount of data.

The idea of a digital computer is an old one. Charles Babbage, Lucasian Professor of Mathematics at Cambridge from 1828 to 1839, planned such a machine, calling it the analytical engine, but it was never completed. Although Babbage had all the essential ideas, his machine was not such a very attractive prospect at the time. The speed that the machine could have worked at would be definitely higher than that of a human brain but something like 100 times slower than that of the Manchester machine, one of the slower of the modern machines itself. The storage was to be purely mechanical, using wheels and cards. The fact that Babbage's analytical engine was to be entirely mechanical will help us to rid ourselves of a superstition that machines can run only on electricity. People often attach importance to the fact that modern digital computers are electrical, and that the nervous system also is electrical. Since the theoretical Babbage machine was not electrical, and since all digital computers are in a sense equivalent, we see that this use of electricity cannot be of theoretical importance. Of course electricity usually comes in where fast signalling is concerned, so that it is not surprising that we find it in both these connections. In the nervous system chemical phenomena are at least as important as electrical. In certain computers, the storage system is mainly acoustic. The feature of using electricity is thus seen to be only a very superficial similarity. If we wish to find such similarities, we should rather look for mathematical analogies of function.

### POSTMODERN AND MODERN DIGITAL MACHINES

We cannot say the computer works fundamentally differently than it did in the past, but today [8] at the 21st century, the most efficient, profound machines rapidly become obsolete. Computers generally have an ability to capture a symbolic representation of

spoken language for long-term storage freed information from the limits of individual memory. In pre modern, not only do books, magazines, and newspapers convey written information, but so do street signs, billboards, shop signs, and even graffiti. The presence of these products of "literacy technology" does not require active attention, but the information to be conveyed was ready for use at a abstract level of information during the premodern computing days.

After the discovery of the internet, technology has been ubiquitous in industrialized countries. A computer today runs billions of instructions per second, stores billions of millions of bits of data, fetches and stores in symphony, and more. Silicon-based information

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Currently, consumers can't, won't and don't read the thousands of reviews for a particular product on an e-commerce site.

technology today, in contrast, is far from becoming part of the environment. More than 100 million personal computers have been sold, but nonetheless, the computer remain largely in a world of its own. In the age of silicon, the number of transistors keeps doubling every three years. These machines will soon be the subjects in the Turing test.

### TESTING A HUMAN AGAINST A SOPHISTICATED MACHINE

Our key question is whether hardware making use of the sophisticated multicore processors can still survive, i.e., can a human being be indistinguishable from a computer that uses powerful machine learning and high powered hardware?

When a user asks a question, such as:

Q: Please write me a sonnet on the subject of the Forth Bridge.

The machine will respond:

A : Count me out on this one. I

never could write poetry.

Below, we observe three other machine responses to human questions:

Q: Add 34957 to 70764.

A: (Pauses about 30 seconds and then gives an answer) 105621.

Q: Do you play chess?

A: Yes.

Q: I have K at my K1, and no other pieces. You have only K at K6 and R at R1. It is your move. What do you play?

A: (After a pause of 15 seconds) R-R8 mate.

These questions were tested a few decades ago with a human and a low powered "not so efficient" system.

Say when the user asks to perform any complex operation, the computer may either respond with the correct or an incorrect answer. Interestingly, if the computer can understand that a test is done, the computer might also deliberately give an incorrect answer.

### CALCULATION OF RESPONSE TIME OF A COMPUTER

The speed of a computer or modern computer is unmatched with the speed of the human brain. A best supercomputer can compute 30 times faster [10] than can an average human bring. A multicore machine today is likely to match the speed of a supercomputer. So, the Turing test fails if the computer doesn't try to trick a human deliberately by applying smart machine learning processes. If a machine today deliberately uses machine learning to trick users, then the Turing test will still work.

### TESTING THE TURING TEST

Asking a computer to throw a object, for example, or asking it for the password will make the Turing test fail in certain circumstances. A computer can do everything except make a physical motion without any external interfaces. This is the major drawback of today's computers, even with more sophisticated current computers. No computer today

can perform physical motion on its own. So, a tester asking the computer “Can you throw that?” might certainly fail the Turing test, unless both the computer and the human can respond “I cannot do that!”, and reject the question from the tester. This question can be handled by a modern multicore machines easily [9] by applying deep semi-supervised learning models in which we apply and use generative models on unlabeled data, such as the commands that users ask machines to handle.

The use of a generative model can help the multicore machine to generate sound. When a user asks a human or machine: “Can you throw a object?”, the human can simply perform the appropriate action; a machine from today can also carry out the task by using a deep semi-supervised model to produce sound resembling an object being thrown. Since there is a physical barrier between the tester and the actors in the test, we can conclude the machine can easily trick the tester and that the Turing test holds true. It is noted that the closed physical barrier is a precondition in this test, so the tester cannot find out whether an audio is been played inside to simulate the falling of object, or if a real object has fallen during the test.

## DEEP SEMI-SUPERVISED GENERATIVE MODELS

We need a tremendous amount of information in the physical world of atoms or the digital world of bits. The data that is to be collected for this model is a collection of real world human data that contains information about the tasks that humans follow day to day. The trick is to develop models and algorithms that can analyze and understand this treasure trove of data.

Generative models [11] are one of the most promising approaches towards this goal. In order to train a generative model, we first collect a large amount of data in daily human tasks (e.g., millions of sentences or sounds, but not images) and then train a model to generate data like it. Generative methods describe the relationship between features  $x$  and labels  $y$  using a joint probability distribution  $p(x, y)$ . As a result, they handle arbitrary queries about the data, such as predicting unknown labels via  $p(y|x)$ , or imputing missing features,  $x$ , using the distribution  $p(x)$ . Discriminative methods, on the other hand, focus only on directly predicting  $y$  from  $x$  via the mapping  $p(y|x)$  (which may or may not correspond to a probability distribution). If prediction is the only goal, this approach will use the model parameters more efficiently, and be more accurate on larger datasets [12]. Alternatively, as per researches of Volodymyr Kuleshov and Stefano Ermon [11], the probability functions can be calculated by specifying two distinct elements of the joint probability distribution  $p(x, y)$ : a discriminative component  $p(y|x)$ , and a generative component  $p(x)$ . Each component may be represented by an arbitrarily complex model, such as a convolutional neural network, or a generative adversarial network. We fit these using a multiconditional objective that assigns a different weight to each component, thus interpolating between a fully discriminative  $p(y|x)$  and a fully generative  $p(x)$ .

## INFERENCE

The Turing test works for today’s computers if and only if the computer uses machine learning to understand a human being. Machines are much more powerful today than they were in the 1950s, when the tests were initially conducted. Since the

1950s, computer growth has far exceeded human growth, and humans cannot match the processing power of sophisticated modern multicore machines. Today, the Turing test will pass if machine learning algorithms such as deep semi-supervised generative models, as mentioned earlier, are applied alongside the test. Thus, we conclude that the Turing test will pass in any real scenario. ■

## CONCLUSION

Some machine, whether a “then” or “now” computer, multicore computer, or supercomputer, will satisfy the correctness of the Turing test. The Turing test can then be used to verify the correctness of other systems built, such as the architecture of software, the working of a real system, or successful human-computer interactions.

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# SIDHARTH VISWANATHAN

Sidharth Viswanathan is an undergraduate student at Velammal Engineering College, Chennai of Class of 2019. He is majoring in CS and is inspired by the research of Alan Turing and presented this work in the honour of Turing’s 106th anniversary. He aims for his work to uncover a new dimension and various techniques to applying The Turing Test and hopes to unlock the next milestone that this test could influence.



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