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Data-Driven Analysis for Causality of Parent–Child Interactions in the Bakken

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Abstract

As unconventional reservoirs mature, fracture interactions between existing wells (parent wells) and newly developed wells (child wells) have a more significant impact on reservoir productivity. In the Bakken Petroleum System (Bakken), which includes the Bakken and Three Forks reservoirs, these parent–child interactions are growing more intense because the average length of time between parent well and child well completion dates has been increasing, resulting in broadening of the pressure depletion zone surrounding the parent wells. During completion of the child well(s), this pressure depletion surrounding the parent well leads to asymmetric fracture growth from the child well(s) toward the parent well. The asymmetric fracture growth eventually impacts production volumes of both the parent and child wells, especially when they are tightly spaced. Therefore, investigating the causality of parent–child interactions and measuring the causal impacts on production are crucial to improving long-term development planning and reservoir performance. This study 1) evaluates the effect of parent–child interaction on productivity by assessing depletion effects and the impact of different completion designs and 2) investigates how refracturing strategies affect parent–child interactions.

There are approximately 17,000 horizontal wells completed in the Bakken, and based on our analysis, approximately 45% of them have parent–child interactions. In this Energy & Environmental Research Center study, several customized data sets were analyzed to quantify production impacts by key features, including well spacing, completion intensity, and parent well depletion estimated by production time and cumulative production. An extensive data mining process was applied to extract key features. A predictive model based on eXtreme Gradient Boosting was developed to estimate production loss by parent-child interactions, which were evaluated by tracking changes of 90-day oil, gas/oil ratio (GOR), and water/oil ratio (WOR) in parent wells after child well completion. By comparing multivariate impacts, key influencing drivers were identified.

The analysis quantified how new child well completions restimulated the “understimulated” parent wells in the Bakken, which improved their production, unlike the Eagle Ford and Permian Basin, where negative parent–child interactions that reduced productivity have been observed. Completion intensity and depletion status of parent wells control the well interactions, especially in drill spacing units with tighter well spacing. The analysis suggests that parent well refracturing strategies can partially offset these effects. Our analysis also shows that overstimulated and depleted parent wells will lead to larger production loss like other basins. In the Bakken, production losses are expected to increase because of the higher depletion effects from existing parent wells. Therefore, future child well completion should be optimized to maximize production.

The present study provides insights on how depletion status and completion parameters affect parent–child interaction and productivity, which can be used to guide the optimal design of child well completions. The analysis developed a novel machine-learning-based predictive model to estimate the production impact of parent–child interactions. Additionally, quantification of rapid production response (90-day oil/GOR/WOR) in a parent well following child well completion is important to estimate long-term productivity from parent–child wells. Our learnings on how to extract key features using an extensive data mining process and insight on how to develop better predictive models can be transferred for parent–child well studies conducted in other basins.

Introduction

Unconventional reservoirs in the United States have been actively developed since the mid-2000s and represent a significant portion of domestic oil production. The successful production of unconventional reservoirs was largely attributable to improved completion technologies and optimization of the resource development, which enhanced well productivity and reduced production costs. As development accelerated, operators in unconventional reservoirs increased completion sizes (greater proppant and fluid use) and drilled more wells per section (tighter spacing) to improve production. Implementation of larger completions and tighter spacing on newly developed wells (child wells) generated complex fracture interactions with existing wells (parent wells). The fracture interactions between parent and child wells have become a major concern for operators as unconventional reservoirs have matured because these interactions can cause a loss of production. During completion of the child well(s), this pressure depletion surrounding the parent well leads to asymmetric fracture growth from the child well(s) toward the parent well. The asymmetric fracture growth eventually impacts production volumes of both the parent and child wells.

Previous studies that evaluated the impact of parent–child well interactions in U.S. unconventional basins showed that these interactions typically have a negative impact on both child and parent wells (Cozby and Sharma, 2022; Lindsay and others, 2016; Xu and others, 2019; Gupta, 2020). This study focused on the Bakken Petroleum System (Bakken), which comprises two primary oil reservoirs—the Bakken Formation and the underlying Three Forks Formation. In contrast with other tight reservoirs like the Woodford in Oklahoma; Eagle Ford in Texas; and Bonespring, Spraberry, and Wolfcamp in the Permian Basin of Texas and New Mexico, where negative parent–child well interactions diminished reservoir productivity, parent–child well interactions in the Bakken generally have a positive effect on parent wells because of “understimulated” Bakken parent wells. However, parent–child interactions in the Bakken are growing more intense because the average length of time between parent well and child well completion dates has been increasing. For example, for wells completed before 2016, the average time difference between parent and child well completions was less than 2000 days, whereas wells completed after 2016 had 2000 –4000 days between completion dates (Figure 1). The increasing time between completion dates results in broadening of the pressure depletion zone surrounding the parent wells. As Parent well production continues, the depleted parent well will establish more intensive communication with future child well(s), resulting in production losses in the child wells (Figure 2).

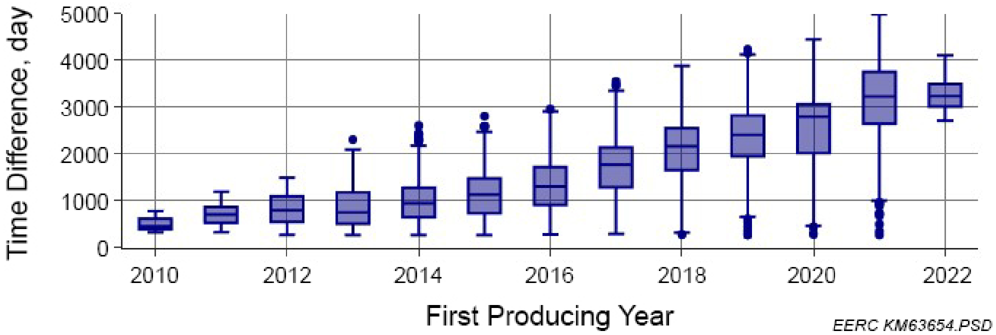


Figure 1. Average time difference between Bakken parent well and child well completion dates.

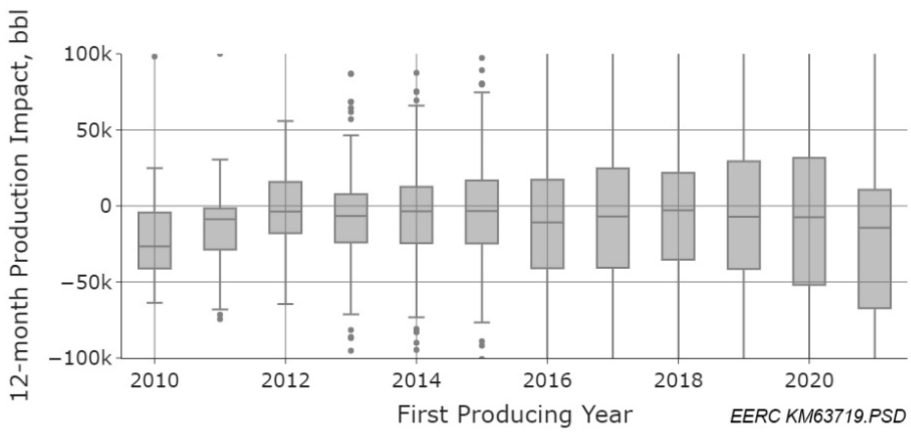


Figure 2. Average production loss in child wells over time.

This Energy & Environmental Research Center (EERC) study investigated the complex interplay of reservoir depletion, well spacing, and completion intensity to examine how these factors impact parent–child well interactions. The primary goal of this study was to utilize machine learning (ML)-based approaches to characterize the causes of production impacts from parent–child well interactions. A secondary goal was to evaluate combinations of well spacing and completion designs to maximize parent–child well production and minimize the risk of frac-hits. Clear understanding of parent–child well interactions can help to formulate successful strategies for infill drilling and completion intensity (proppant and fluid volumes). As the average time difference between parent and child well completion dates has been increasing over time, reservoir depletion plays an increasingly important role for parent–child interactions. This study also investigated the impact of parent well refracturing on parent–child well interactions and strategies to reduce frac-hits and promote uniform fracture growth while stimulating child wells.

Methods

Data Mining Process

To characterize the causes of production impacts from parent–child well interactions, several complementary data analytics methods were developed and applied in this study. First, new well completion and production data were acquired to capture the most recent data, and these data were cleaned by removing outliers and anomalies. Second, several data-mining methods were developed to extract key features from several data sets and assimilate these data into a single database. Well trajectory data were processed to identify parent–child well pairs developed in parallel geometries and to calculate well spacing using multiple trajectory points. Monthly production data were used to derive metrics like oil rate, gas/oil ratio (GOR), and water/oil ratio (WOR) for the parent wells before and after the child well completion. Third, several ML models were developed to quantify parent–child well interactions. These ML-based prediction models were used to estimate the production impact caused by the well interactions. Lastly, several data visualization methods were used to show how depletion status of the parent well and completion designs affect the parent–child well interactions. Python codes were written to manage several different data sets, including North Dakota Industrial Commission (NDIC) data, Enverus (DrillingInfo) data, geologic information (EERC-generated), monthly production, and well trajectory data. Parent wells were identified for each drilling spacing unit (DSU) based on their completion dates. To define the parent–child well relationship, the following criteria were established:

- A maximum of 1500-ft horizontal and a maximum of 100-ft vertical distances between wells.
- At least 9 months or more of production in the parent well before completion of the child well(s).
- Only parallel geometry parent–child well pairs were included to avoid data noise introduced from complex parent–child well geometries and interactions.
- Both parent and child wells have similar length of their horizontal sections.
- Parent and child well pairs were completed by the same operator to minimize flowback differences.

The next step was to calculate well spacing for each parent–child well pair. To calculate spacing between wells, an improved algorithm was developed using multiple points from the well trajectory. The well trajectory shapefile was downloaded from NDIC and processed to select center and bottomhole points along the well horizontal section. In the Bakken, well trajectories are complicated, and some well pads had complex (nonparallel) development geometries and different well lengths between parent and child wells. In Figure 3, the bold lines represent previously developed parent wells, while the other lines are newly developed child wells. If only one center point of the well trajectory is used to calculate well spacing, then it is difficult to distinguish nonparallel well pairs from parallel well pairs. To analyze the parent–child well interactions, only parallel geometry parent–child well pairs were considered in this study. DSUs having complex (nonparallel) geometry development patterns and unequal well lengths were excluded from the analysis, resulting in a total of 12,466 wells used for this study.

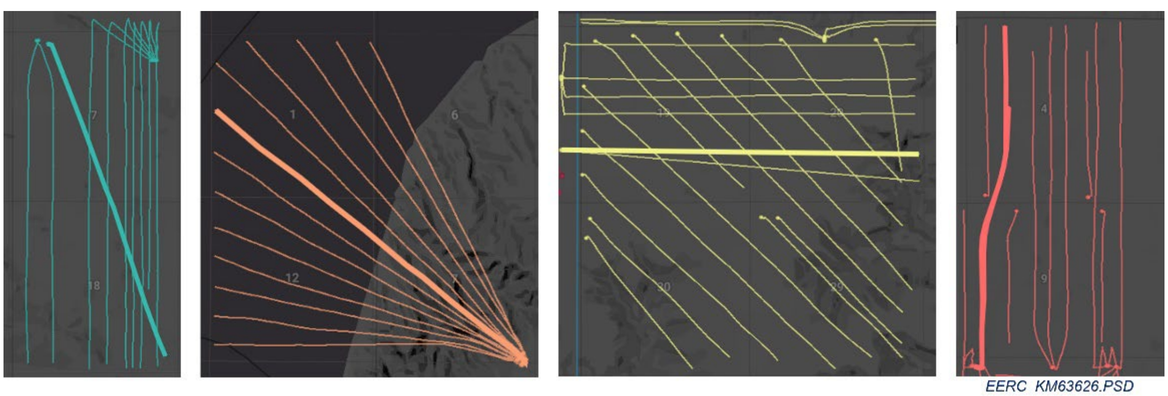


Figure 3. Examples of complex (nonparallel) geometries for four different DSUs in the Bakken. Bold lines are parent well trajectories, and the thinner lines are the well trajectories of the child wells. Complex DSUs like these were excluded from the parent–child well interactions analysis (source: Enverus, 2023).

Results and Discussions

Parent–Child Well Development in the Bakken

In the Bakken, parent–child well interactions have significantly increased over recent years. Most parent wells were developed from 2010 to 2014. Beginning in approximately 2013, operators focused on child and codevelopment wells within the core area of the Bakken (Figure 4). Based on calculations made in this work (Table 1), about 19% of the wells were indicated as parent wells, while 25% of the wells were indicated as child wells. Thus, as of March 2022, a total of 44% of Bakken wells have been influenced by parent–child interactions. The average calculated time difference between parent and child for wells completed before 2016 was 2.9 years and for wells completed after 2016 was 6.2 years.

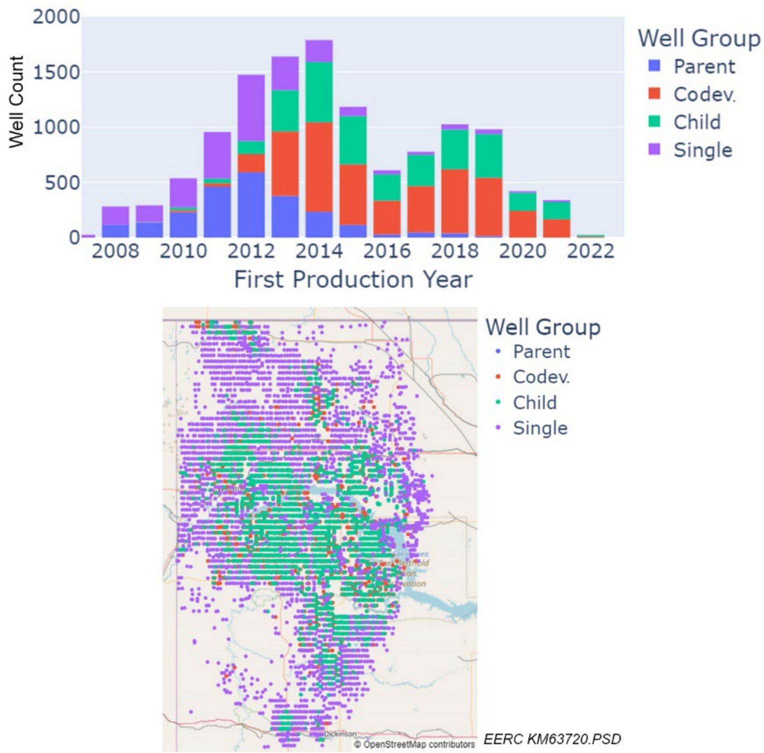


Figure 4. Well counts of the categorized well group by first producing year (a) and location of the categorized Bakken wells (b).

Table 1. Number of Wells by Well Group

Well Group	Well Count	Percent
Parent	2393	19%
Child	3168	25%
Codev.	4452	36%
Single	2453	20%

Completion Strategy for Parent–Child Wells in the Bakken

Most parent wells were stimulated using older, smaller completion designs; average values of proppant and fracturing fluid for the parent wells were 351 lb/ft and 7.5 bbl/ft, respectively. When operators developed child wells, newer and larger completion designs were implemented as the completion technology evolved, with nearly twice the proppant (630 lb/ft) and fracturing fluid (14.8 bbl/ft). Comparisons between parent and child wells for several completion parameters are summarized in Table 2 and Figure 5. To avoid biased (asymmetrical) fracture growth toward the depleted parent well, operators applied a wider well spacing to the parent well than to codeveloped wells (711 vs. 578 ft). By applying the wider well spacing between parent–child wells, operators tried to reduce production impacts from direct fracture communication. In addition to different completion designs, operators implemented stacked targeting strategies for child well development, drilling and completing child wells in the Three

Table 2. Completion Design for Parent-Child Development in the Bakken

	Parent	Child
Well Spacing, ft	711	578
Injected Proppant, lb/ft	351	630
Injected Fluid, bbl/ft	7.5	14.8
Stage Count	29	37

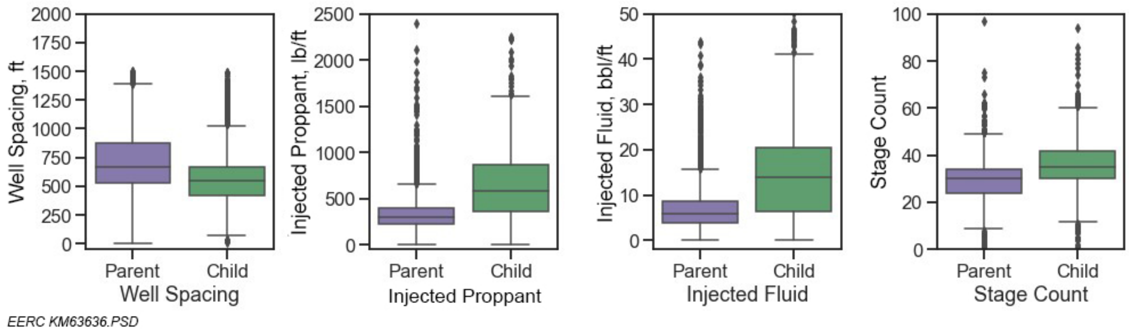
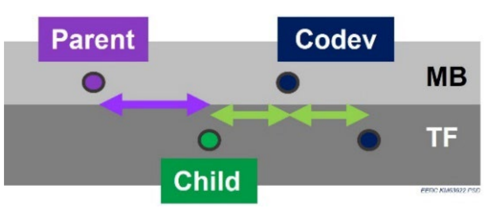


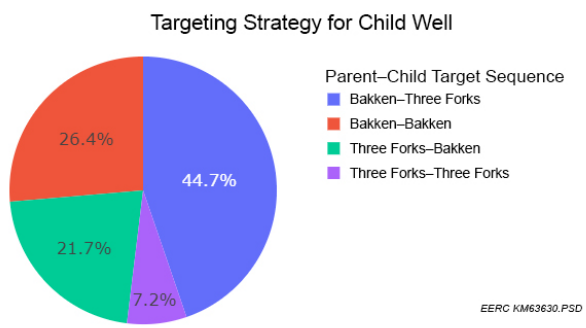
Figure 5. Completion strategy for parent and child wells in the Bakken.

Forks Formation if the parent well had been completed in the Bakken Formation (Bakken–Three Forks) or the Bakken Formation if the parent well had been completed in the Three Forks Formation (Three Forks–Bakken), rather than developing child wells in the same formation as the parent well (Bakken–Bakken or Three Forks–Three Forks). By applying stacked targeting, operators tried to avoid direct fracture communication between wells. Figure 6(a) describes the general completion strategies for parent–child well development in the Bakken. Stacked targeting strategies accounted for about 66.4% of parent–child development (the sum of Bakken–Three Forks and Three Forks–Bakken in Figure 6[b]).

Figures 7 and 8 show that Bakken operators implemented generally similar completion strategies for child wells, which was wider spacing for the parent well and larger/newer completion designs for child wells. However, each operator used slightly different strategies for parent–child well development. For example, Operator C implemented a wider spacing (parent–child) than other operators, but their child well completion design was like other operators. Operator I used a different well-spacing strategy than other operators by implementing similar well spacing to both the parent and codevelopment well. The differences in completion design will impact production of both the parent and child well.



(a)



(b)

Figure 6. (a) Illustration of parent–child well development in the Bakken. (b) Tageting sequence pattern for parent–child development in the Bakken.

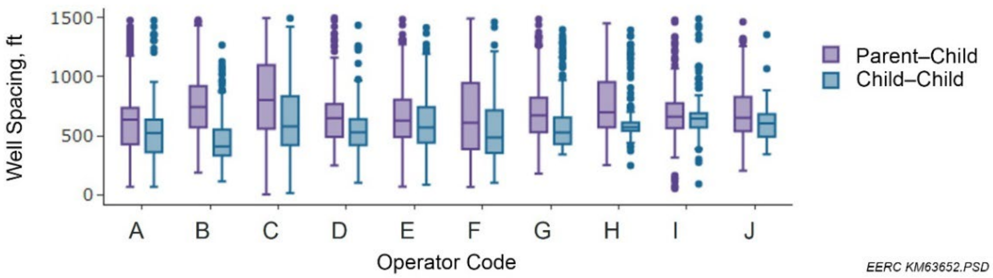


Figure 7. Well-spacing strategy by operator.

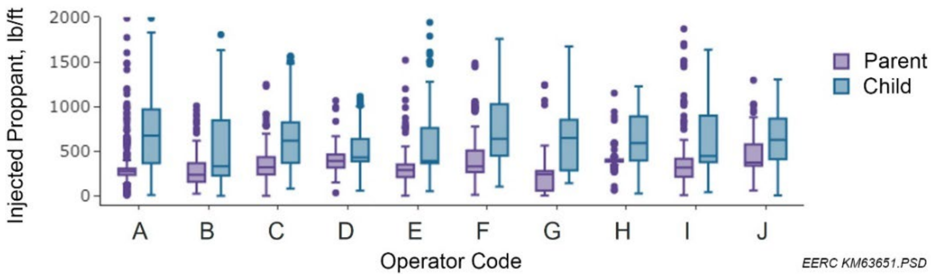


Figure 8. Proppant volume difference in parent and child wells by operator.

Production Impacts on the Parent Well

The parent–child well interactions cause production changes in both parent and child wells because of the asymmetric fracture growth from the child well to the depleted parent well. In this section, short-term production changes in parent wells are investigated to quantify how the fracture interactions impacted parent well production as a function of parent well depletion status and completion intensity.

Many parent wells were understimulated using older, smaller completion designs. Consequently, child well completions might stimulate the unstimulated region surrounding the parent well by growing fractures toward the depleted pressure zone, which would increase production in the parent well (Figure 9). Because fracture growth from the child well could pressurize the parent well, GOR in the parent well can increase temporarily. Finally, WOR in the parent well could increase from the influx of fracturing fluid from the child well and from the larger stimulated reservoir volume (SRV) connections between the child and parent well. To quantify the production impact in the parent wells, average changes of 90-day oil rate, GOR, and WOR before and after child well completion were investigated in 2393 parent wells (excluding refractured parent wells).

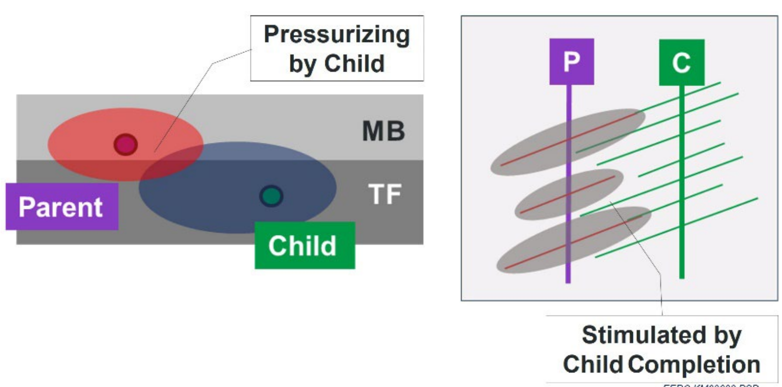


Figure 9. Illustration explaining how the child well influences production in the parent well.

Production Changes in Parent Wells Caused by Child Well Completion

Figure 10 summarizes the average changes in oil rate, GOR, and WOR in parent wells (excluding refractured parent wells) within 90 days of child well completions. Parent well oil rates increased by about 75%, GORs decreased about 8%, and WORs increased about 122% by stimulating (pressurizating) from child well completion. The short-term WOR's increase might be impacted from injected frac fluid in child well(s) and formation water production within newly stimulated/connected SRVs. Long-term parent well production changes are different than the short-term changes. Parent oil rates decline sharply, GORs increase, and WORs continue to increase over time because of connected fracture network growth. Each child well completion may impact production in parent wells differently because of well spacing, completion design, and depletion status. Figure 11(a) shows an example for a representative parent well from the database, showing the increased oil rate, decreased GOR, and increased WOR following the child well completion on October 29, 2018.

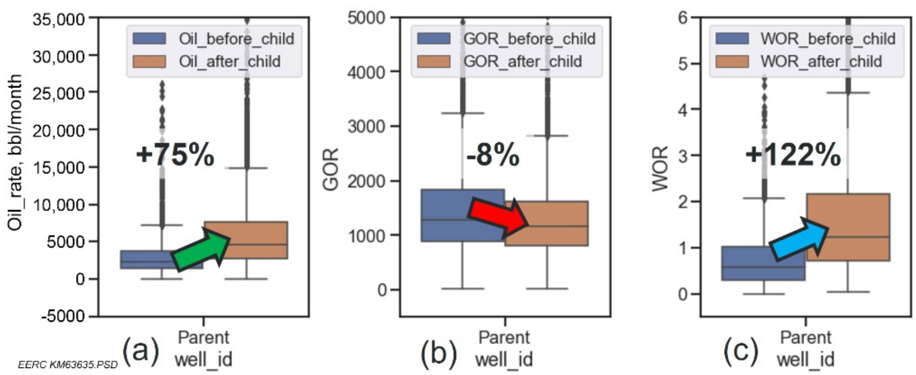
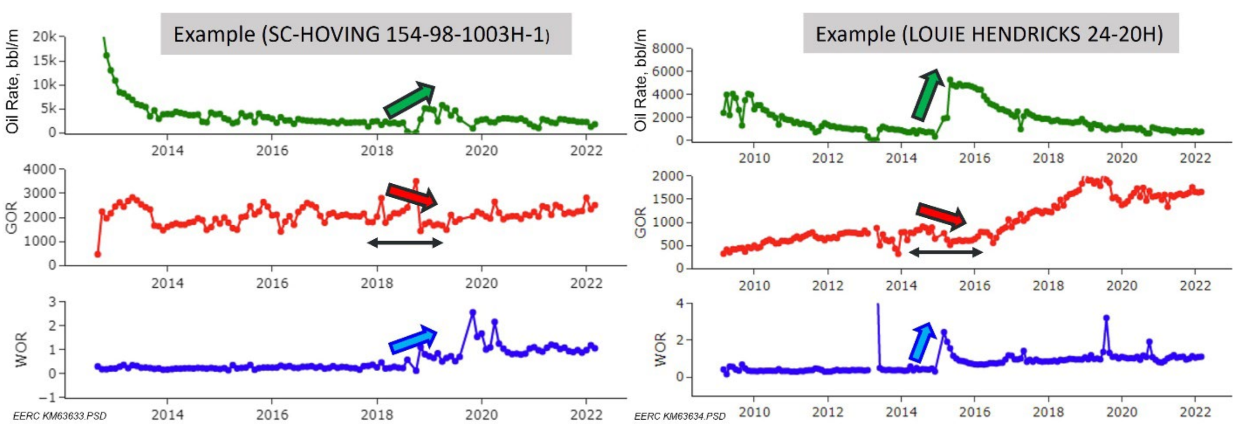


Figure 10. Average changes (%) in 90-day oil rate, GOR, and WOR in parent wells after child well completion calculated based on 2393 parent wells.



(a) (b)

Figure 11. (a) Production response in parent well (SC-HOVING 154-98-1003H-1) after child well completion. The black arrow in the middle panel shows the approximate 1-year window following child well completion on October 29, 2018. (b) Production response in refractured parent well (Louie Hendricks 24-20H) after child well completion. The black arrow in the middle panel shows the approximate 1-year window following child well completion on March 12, 2015.

Production Changes in Refractured Parent Wells

Since 2009, Bakken operators have implemented a refracturing strategy to boost production from understimulated wells. To date, the EERC has identified 341 wells in the North Dakota portion of the Bakken that were refractured before October 2021 (Dalkhaa and others, 2020, 2018; Zhao, 2023). Seventy-eight refractured parent wells from this list had child wells that were restimulated to prevent asymmetric fracture growth and to increase production. The completions for the refractured parent wells used smaller proppant (210 lb/ft) and larger fluid (8 bbl/ft) amounts in comparison with the original completion design (280 lb/ft and 5.6 bbl/ft, respectively) (Table 3).

Typically, the main objective of the parent well refracturing is to create new stimulated volume to boost production of the refractured well and a secondary objective is to increase reservoir pressure in the depleted zone to prevent excessive fracture interactions with child wells. However, there is a combination of impacts on production in parent wells after refracturing in the parent well and completion of the child well. For the 78 refractured wells in the database, the 90-day oil rates in the refractured parent wells jumped by 590%, presumably due to the newly created fractures from the refractured parent and child wells. Pressurizing the depletion zone by refracturing lowered 90-day GORs by 4.4% temporarily, after which GORs continued to increase with ongoing production from the reservoir. Finally, the 90-day WORs showed a rapid increase of 257% when the refractured wells were opened again after recompletion, presumably due to the flowback of fracturing fluid (Figure 12). After the flowback effect, the WORs continued to trend upward. Figure 11(b) shows an example for a representative refractured parent well from the database, showing the increased oil rate, decreased GOR, and increased WOR following the child well completion on March 12, 2015.

Table 3. Comparison of Completion Design in Parent and Child Wells in the Bakken

	Stim Proppant, lb/ft	Stim Fluid, bbl/ft
Parent – Original	280	5.6
Parent – Refrac	210	8.0
Child	750	18.0

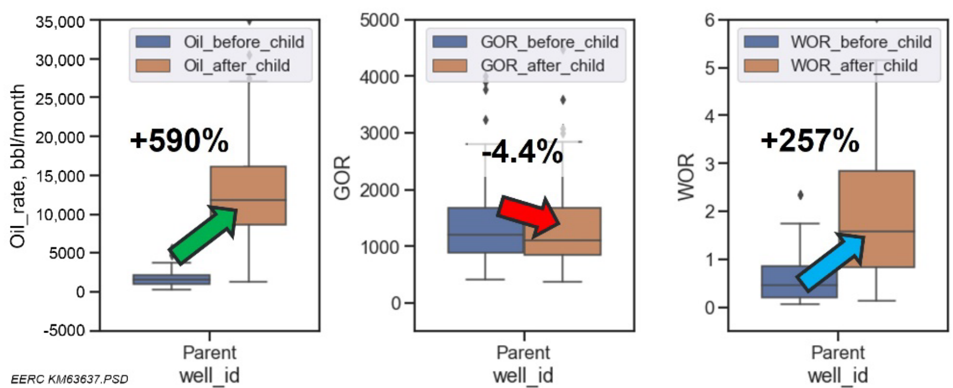


Figure 12. Changes in 90-day oil rate, GOR, and WOR in refractured parent wells after child well completion.

Key Drivers of Parent Well Production Performance

The depletion status and completion design in the parent and child wells affect production in the parent well after the child wells have been completed. The depletion status in the parent well can be represented by the time difference between parent and child well completions and the cumulative production of the parent well. In addition, how the parent and child wells were completed affects the production of the parent well after the child wells have been completed. Therefore, predictive modeling using XGBoost was used to examine the relationship between a target variable of oil rate change in the parent well and five predictors: 1) time difference between parent and child well completions, 2) cumulative production of the parent well, 3) proppant amount used in the parent well, 4) proppant amount used in the child well, and 5) well spacing of the parent well. Proppant and fracturing fluid were highly correlated; therefore, proppant was used as the proxy for completion intensity rather than including both variables in the same predictive model. Figure 13 shows the results of the XGBoost predictive modeling. The values of

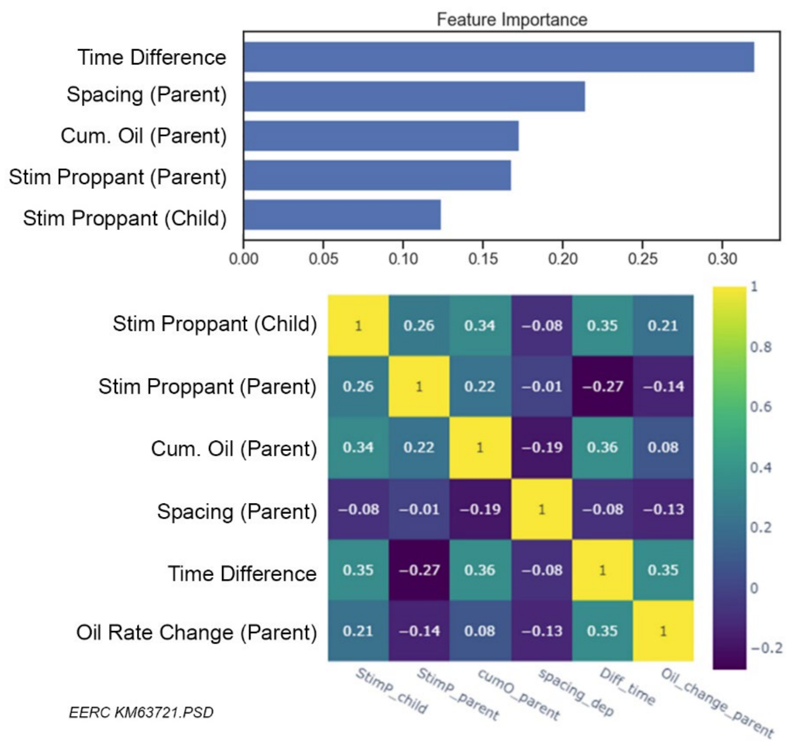


Figure 13. Correlation matrix and feature importance for parent well production impact.

correlation coefficients below 0.4, shown in Figure 13, suggest weak correlations among the five features. However, each feature demonstrates a significant effect on the oil production rate in the parent well. The XGBoost feature importance graph shows that completion time difference has the most influence on the oil rate change in the parent well, followed by spacing, cumulative oil production in the parent well, and proppant amounts used in the parent and child wells.

i. <u>Depletion Effect on Parent–Child Well Interaction</u>

As shown by the XGBoost feature importance plot, the time difference between parent and child well completions and the cumulative production of the parent well, which are proxies for well depletion status, were significant features for predicting the oil rate change in the parent well following child well completion. Pressure depletion in the parent well impacts fracture growth in the child well by altering the in situ stress status. When parent wells have been in production for a longer period, pressure is depleted through a deeper fracture zone (discussed below). Fractures from the stimulated child well grow farther into the depleted zone surrounding the parent well. This deeper fracture growth increases fracture interactions between the parent and child wells. For example, the oil rate in parent wells increased by more than 210% when the parent well produced longer than 2500 days (6.8 years) (Figure 14). Cumulative production volume in the parent well also depends on depletion status, so when the cumulative production is larger, the oil rate changes are more pronounced. For example, the oil rate change exceeded 103% for parent wells that had more than 300,000 bbl of cumulative oil production prior to the child well completion (Figure 15). The predictive modeling suggested that completion time difference has more influence on the oil rate change than the cumulative production volume, which implies that the longer a parent well is in production, the stronger the interactions will be between parent and child wells.

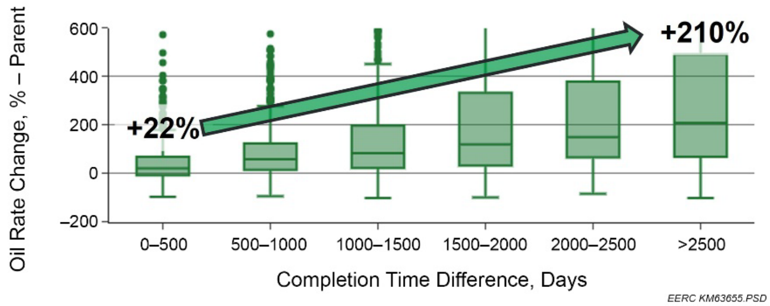


Figure 14. Changes in 90-day oil rate in parent wells by completion time difference.

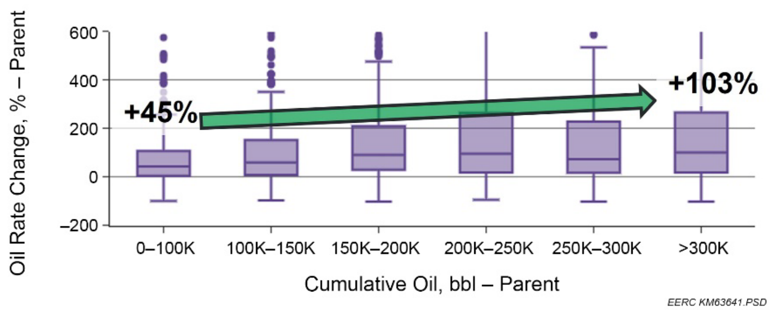


Figure 15. Changes in 90-day oil rate in parent wells by cumulative oil production.

ii. *Completion Effect on Parent–Child Well Interaction*

As shown in Table 3, parent wells were stimulated using older/smaller completion designs while child wells have been stimulated by newer/larger completion designs. The completion combination in parent and child well influences fracture growth in child wells. The intensity of parent–child well interactions increased as well spacing tightened. When the well spacing was tighter (200–500 ft), the 90-day oil rates increased by 104% on average. Conversely, when the well spacing was wider (greater than 1100 ft), the parent–child well interactions were weaker, and the 90-day oil rate only increased by 44% on average (Figure 16). Because fracture growth is controlled by stimulation completion size, fracture length is generally longer when more fluid/proppant is injected into reservoir. Therefore, production in parent wells was more impacted when the completion size of the child well was larger. Figure 17 shows that when completion size was greater than 1000 lb/ft, oil rate in the parent well increased by 123%.

In the Bakken, most parent wells (83%) were completed by smaller completions under 450 lb/ft (Table 4). These understimulated parent wells have received production benefit from the child wells. As illustrated in Figure 18(a), unstimulated reservoir volume remains near the parent well completed by older/smaller designs, and this area could be restimulated by the child well completion. However, when the parent well was completed by a newer/larger design, there was less unstimulated reservoir volume remaining. Consequently, the fully stimulated parent well did not receive as significant a production benefit from the child well completion. Figure 18(b) illustrates this phenomenon, showing that oil rate increased by only 27% when the initial completion size was larger in the parent well (greater than 1000 lb/ft) as compared to older/smaller completion sizes less than 150 lb/ft. This demonstrates that the child well completion has much less impact on the fully stimulated parent well.

Child wells received a production benefit from the understimulated parent wells by sharing the unstimulated reservoir volume. However, when the parent wells were fully stimulated, the child wells did not receive the production benefit. In the following section, production impact in child wells is discussed in more detail.

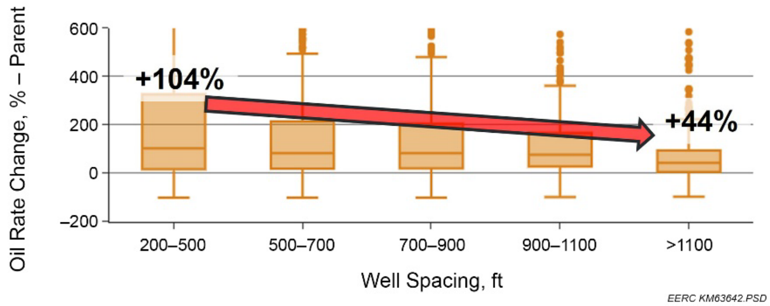


Figure 16. Changes in 90-day oil rate in parent wells by well spacing.

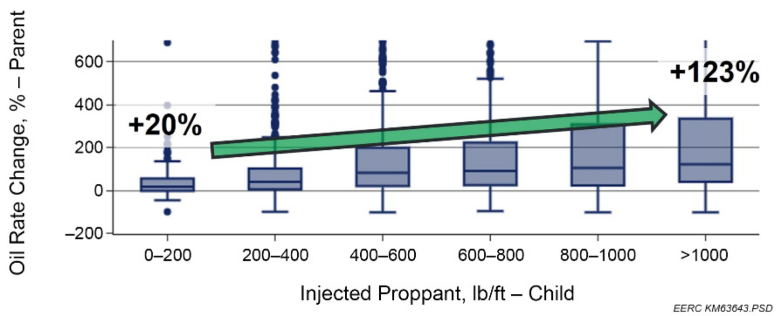
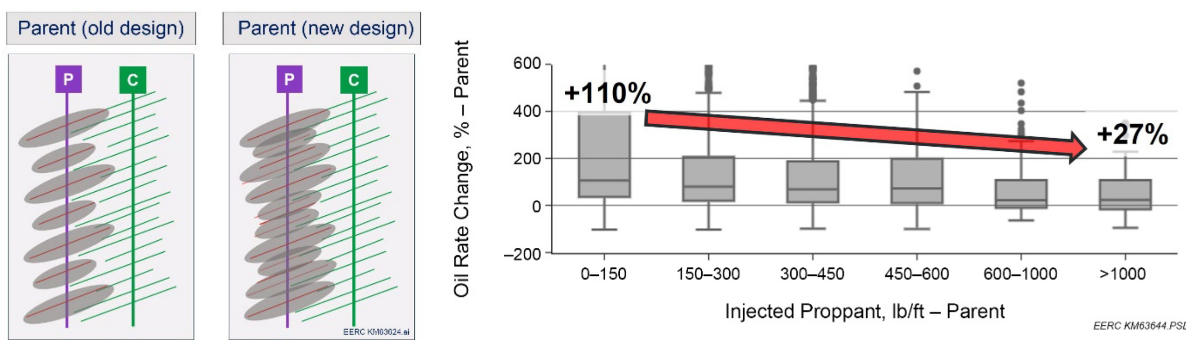


Figure 17. Changes in 90-day oil rate in parent wells by proppant amount (lb/ft) applied in the child well.

Table 4. Parent Well Count by the Proppant Volume (lb/ft) Used in the Stimulation Job

Injected Proppant in Parent Well, lb/ft	0–150	150–300	300–450	450–600	600–1000	>1000
Well Count	300	955	936	224	152	80



(a) (b)

Figure 18. (a) Illustration of parent–child interaction for old (left) and new (right) parent well completion designs. (b) Changes in 90-day oil rate in parent wells by proppant amount (lb/ft) of the parent well.

Production Impact in Child Well

Parent–child interactions typically cause production impact in the child well because stress changes in the depleted zone do not allow development of a symmetrical fracture network during stimulation. Depleted pressure zones surrounding parent wells redirect fracture energy from child wells, and the completion efficiency of child wells is reduced. Because of the lower completion efficiency, child wells cannot produce as expected. Average proppant use, well spacing, and 12-month cumulative oil production were compared among parent, child, and codevelopment wells (Table 5). This analysis shows that child wells produced lower volumes of oil compared to codevelopment wells (125 versus 135 Mbbl) despite similar proppant use (579 and 590 lb/ft) and wider spacing implemented in the child wells (645 versus 570 ft). The production impact in child wells is affected by various factors, including depletion and completion parameters. In this section, a predictive model was developed to quantify the production impact and to better understand the factors affecting production impact.

Table 5. Average Completion Design for Parent, Child, and Codevelopment Wells

	Avg. Inj. Proppant, lb/ft	Avg. Spacing, ft	Cum. 12-m Oil, Mbbl
Parent	300	711	103
Child	579	645	125
Codev.	590	570	135

Predictive Model to Estimate Production Impact

To estimate production impact in child wells, the method used here first evaluated the expected production volume in the absence of parent–child interactions. The first step was identifying wells that did not have parent–child relationships. Codevelopment wells, which are developed together with child wells, were used to understand well production without the parent–child interactions. The parent–child interactions could impact the production of a second-child well, which was observed in other basins, including the Permian and Eagle Ford (Cozby and Sharma, 2022). However, the production interference with second-child wells was not observed in the Bakken, based on comparison between first-, second-, and third-child wells. The second step was developing a predictive model to estimate cumulative 12-month oil production for wells without parent–child interactions. The XGBoost regression predictive model was built using 20 features, including completion and geology parameters. The well production, completion, and geology data were randomly split into training and testing data sets by 0.8:0.2 (i.e., 80% of the wells were used to train the model, and 20% of the wells were used to test the model). The training set was used to develop the XGBoost model, and the model performance was evaluated using the test set. The model performances on the training and test tests are shown in Figure 19, which showed good performance on the test set (R-squared of 0.719). The feature importance plot from the XGBoost model shows that stimulated proppant volume was the most influential factor for well production. Among geological features, the producing formation (Bakken versus Three Forks) and initial reservoir pressure were important features for well production, with wells completed in the Bakken and in locations with higher initial reservoir pressure having greater production (Figure 19). The third step of analysis calculated the production impact of each child well using the following formula:

Production Impact (child well) = Actual Production (under parent–child interactions) – Predicted Production (no parent–child interactions).

In other words, the observed well production was compared to the predicted well production with no parent–child well interactions, and wells that produced less than predicted would have lost production, i.e., negative values. The feature engineering of production impact as the target variable allowed us to investigate the impacts of depletion and completion features on the production impact in child wells.

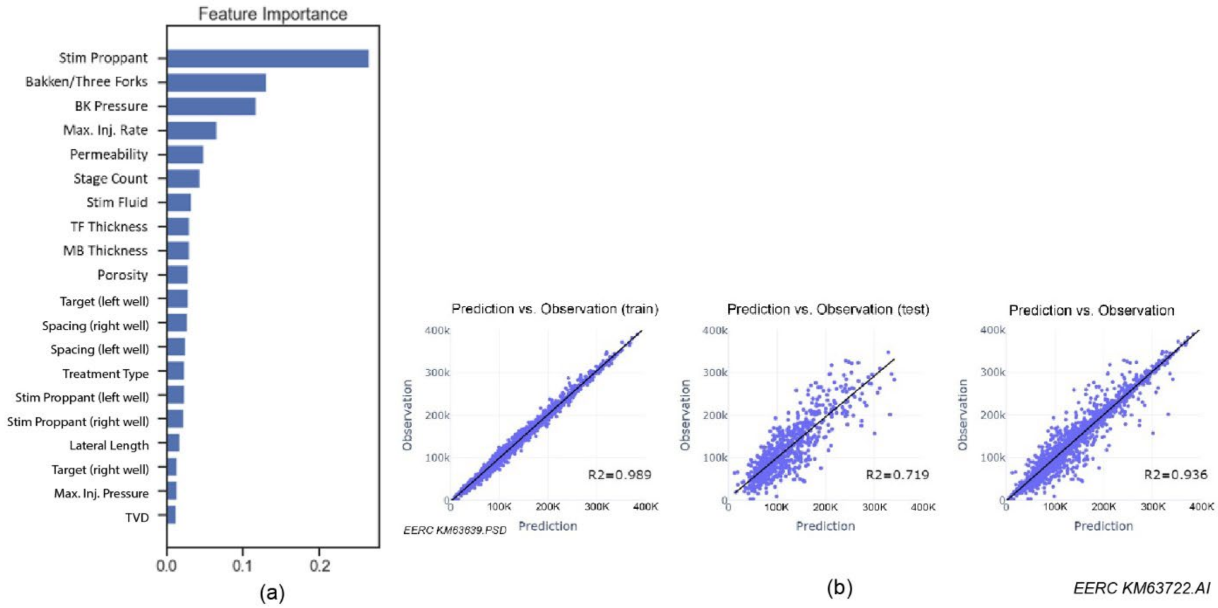


Figure 19(a) Feature importance calculated from the XGBoost model used to estimate production impact. (b) Performance of the XGBoost model on the training set (left panel), test set (middle panel), and the full data set (right panel).

Impact of Parent Well Production and Completion Size

Analogous to the preceding section on production impacts to the parent well, production impact in child wells can be influenced by interactions between depletion and completion factors. Like before, depletion status was characterized by cumulative production and the production time of the parent well, and the completion size was characterized by proppant amount and well spacing. The original completion design in the parent well influenced the production in the child well, as shown in Figure 20. When the completion size of the parent well was greater than 1000 lb/ft, the production in the child well decreased nearly 25% (roughly 50,000 bbl of lost production relative to the analogous case with no parent–child well interactions). Even in case of smaller completion sizes in the parent wells with less than 150 lb/ft, child well production was decreased about 6% because of the parent–child interactions (Figure 20). Similarly, the cumulative production volume from the parent well also affected the production in the child well. As cumulative production of the parent well increased from 100,000 bbl to more than 350,000 bbl, the estimated child well production impact ranged from −9.7% to −14%, respectively (Figure 21).

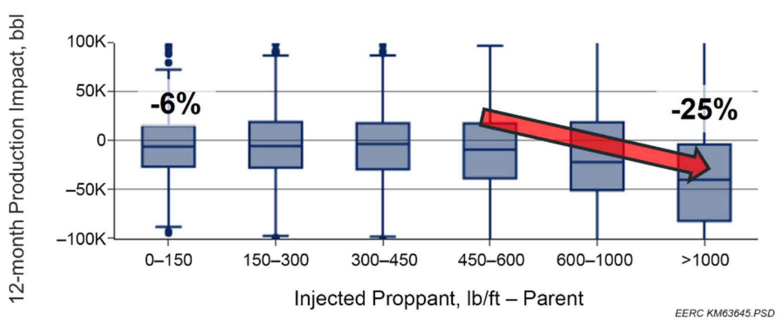


Figure 20. Production impact in the child well by stimulated proppant in the parent well.

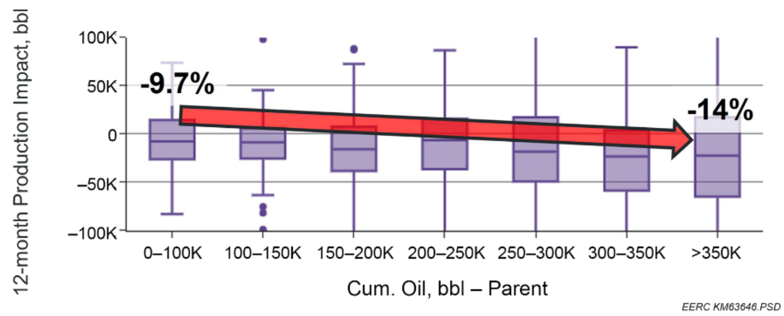


Figure 21. Production impact in the child well by cumulative production of the parent well.

Impact of Child Well Completion and Well Spacing

Well spacing and completion size of child wells also influence production in child wells. Within tighter well spacing (less than 800 ft), when completion intensity in the child well has increased, the production loss in the child well also increased. For example, when well spacing was less than 400 ft and proppant in the child well completion was greater than 1300 lb/ft, the child well could lose up to 40,000 bbl of first 1-year production (Figure 22, upper left-hand corner). When well spacing was greater than 800 ft, the parent–child interactions were weaker and the child well did not lose much production. For example, for cases where well spacing was greater than 800 ft, the estimated child well production impact was –2.7% to +3.8% when the proppant used in the child well ranged from less than 500 lb/ft to greater than 1300 lb/ft, respectively (Figure 23). This result indicates that well spacing is a critical factor for predicting parent–child interactions and 800 ft of spacing is a potential threshold of the fracture interference in the Bakken. When spacing between parent and child well is tighter (less than 800 ft), the parent–child interactions are stronger and production loss in the child well increased. For example, for cases where well spacing was less than 800 ft, the estimated child well production impact was −5.2% to –15% when the proppant used in the child well ranged from less than 500 lb/ft to greater than 1300 lb/ft, respectively (Figure 24). However, wider well spacing will reduce production benefits to understimulated parent well(s), as discussed above. Therefore, the child well development should be optimized based on the overall production and economics of an entire DSU development.

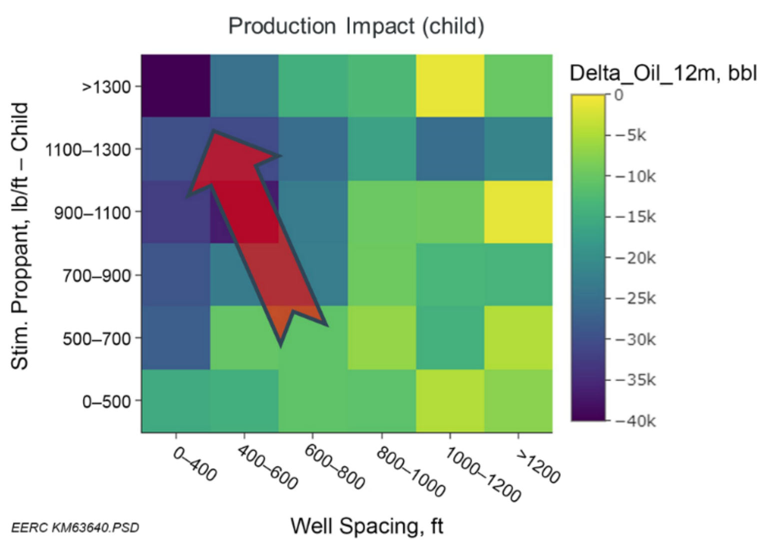


Figure 22. 12-month production impact in the child well by well spacing and injected proppant in the child well.

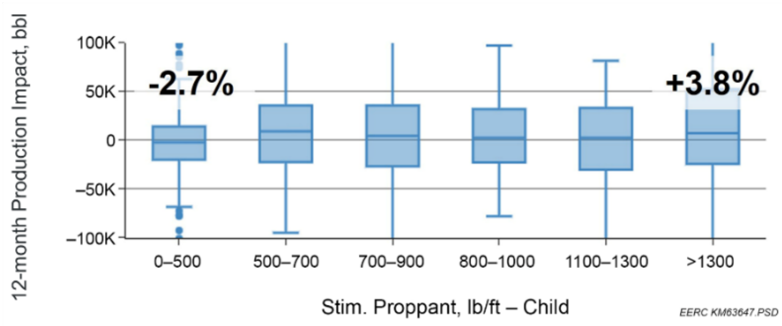


Figure 23. 12-month production impact in the child well by proppant amount applied in the child well for cases where well spacing exceeded 800 ft.

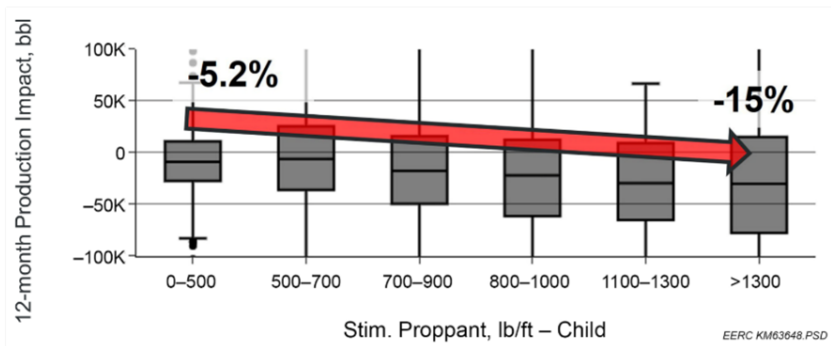


Figure 24. 12-month production impact in the child well by proppant amount applied in the child well for cases where well spacing was less than 800 ft.

Impact of Parent Well Refracturing

As discussed above, refracturing of the parent well affected the parent–child interactions because the injected fracturing fluid pressurized the depleted reservoir area and altered stress fields, impacting fracture growth from the child well. Child wells interacting with refractured parent wells had less production loss than equivalent child wells where there was no refractured parent well. For example, in child wells interacting with refractured parent wells, when well spacing ranged from less than 400 ft to greater than 1200 feet, the child well production impact ranged from −9% to +5%, respectively (Figure 25). In contrast, in child wells where there was no refractured parent well, when well spacing ranged from less than 400 ft to greater than 1200 feet, the child well production impact ranged from −15.4% to +0.6%, respectively (Figure 26). Therefore, especially when the parent and child wells were tightly spaced, refracturing of the parent well reduced the child well production losses by alleviating the intensive parent–child well interactions caused by pressure depletion of the parent well.

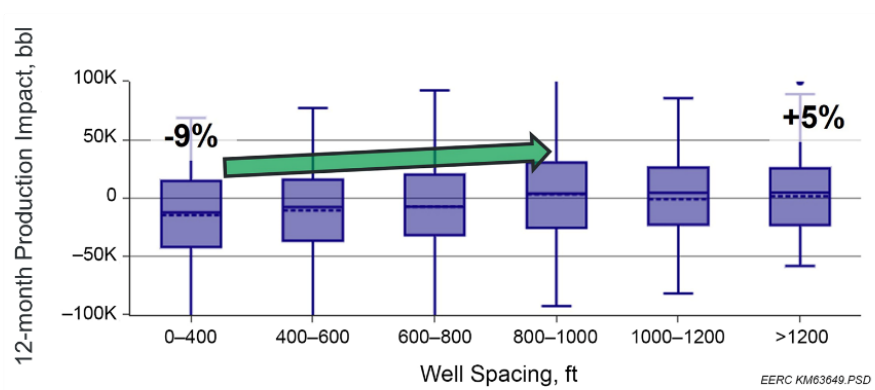


Figure 25. 12-month production impact in the child well interacting with refractured parent well.

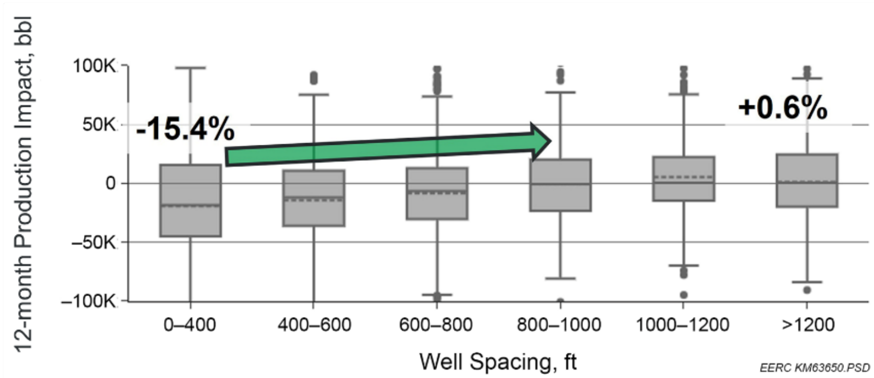


Figure 26. 12-month production impact in the child well under the scenario when refracturing was not implemented in the parent well.

Conclusions

Measuring the impact of parent–child well development and well interactions is important to understand the potential degradation of well performance and well interference from newly drilled infill wells. This study examined the effects of reservoir depletion and fracture interactions on production in parent and child wells. The impact of the parent–child interactions was measured by investigating the oil rate response in parent wells and production impact in child wells. Five well design parameters were examined to quantify the effects of the parent–child interactions: 1) well spacing, 2) injected proppant in the child well, 3) injected proppant in the parent well, 4) time difference between parent and child well completions, and 5) cumulative oil production of the parent well.

Key findings of this study were:

- Reservoir depletion in parent wells impacts fracture growth in the child well by altering the in situ stress status. Fractures from the stimulated child well grow farther into the depleted zone of the parent well that had been producing for a longer time. This deeper fracture growth increases fracture interactions between parent and child wells.
- To reduce impacts from the direct fracture communication, Bakken operators have applied a wider parent–child well spacing of 711 ft and a tighter child–child well spacing of 578 ft. About 66.4% of the parent–child well developments in the Bakken used stacked targeting strategies between the Bakken and Three Forks Formations to avoid direct fracture interactions.
- Well spacing is one of the key features to control parent–child interactions in the Bakken. This study showed that the parent–child well interactions increased with tighter well spacing (less than 800 ft), while the interactions were weak when the well spacing was wider (greater than 800 ft).
- Within the tighter well spacing (less than 800 ft), the completion intensity of the child well controls the parent–child well interactions. With increasing completion size of the child well (greater proppant use), production loss of the child well and the oil rate response of the parent well increase because of stronger fracture communications.
- Initial completion design of the parent well impacts the parent–child well interaction. Understimulated parent wells from older, smaller completion designs left unstimulated reservoir volume. Fractures from the child well stimulate the unstimulated volume, and this stimulation provides production benefit to the parent well and offsets the production losses of child wells. However, when the initial completion size of the parent well was greater than

approximately 450 lb/ft, the production loss of the child wells was greater, increasing by as much as 25%.

- In the Bakken, it is known that parent wells have been positively impacted from newly developed child well completion. This is because most Bakken parent wells (83%) were completed by smaller completions using proppant amounts of 450 lb/ft. Therefore, these understimulated parent wells have received production benefits from the child wells.
- Refracturing strategies were implemented in parent wells to boost production by creating newly stimulated volume and to prevent excessive fracture interactions with child wells by increasing reservoir pressure in depleted zones near parent wells. Refracturing helps to reduce the production loss of child wells by relieving intensive parent–child well interactions, especially for tightly spaced parent–child wells.

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